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Volume I

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MATERIAL CHARACTERIZATION, PART A MECHANICAL PROPERTIES OF TWO METALS AT SEVERAL STRAIN RATES

S. A. EMERY

University of Dayton Research Institute
Dayton, Ohio 45469

May 1982

Interim Report for period 1 October 1977 - 30 November 1979

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>This report describes mechanical property data collected in support of a fan blade analysis model. The development of the blade model is part of a foreign object damage (FOD) study of jet engine fan blades. Use of the properties in the model allows one to evaluate potential fan blade materials. Part A of this report contains a discussion of the mechanical property tests conducted on two metallic materials: 410 stainless steel and 8Al-1Mo-1V titanium. These two materials were selected because

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of their use in the J-79 blade and the F-101 blade respectively. Part B of the report contains a discussion of mechanical property tests conducted on the two composite components of a hybrid composite blade: boron/2024 aluminum and stainless steel wire mesh. These two composites are used in the hybrid composite APSI blade.

Static, quasi-static and dynamic tensile tests were conducted on the metallic materials because (1) studies indicate that metallic mechanical properties exhibit strain rate dependence and (2) tests conducted on full scale blades show that various locations on the fan blades load at different rates. The mechanical properties measured include Young's Modulus (when obtainable), Poisson's ratio (when obtainable), the yield strength, the ultimate strength, and the ultimate strain. The density of the materials was also measured.

FOREWORD

This report describes a contractual work effort conducted for the General Electric Company, Aircraft Engine Group under Purchase Order No. 200-FBA-14K-47844 which is a subcontract of F33615-77-C-5221.

This report covers work conducted during the period of October 1977 to November 1979 and is part of Task IV-A.

The GE Program Manager was Mr. Joe McKenzie and the Principal Investigator was Mr. Al Storace. The work reported herein was performed under the direction of Susan A. Emery, Experimental and Applied Mechanics Division, University of Dayton Research Institute.

Technical support was provided by Mr. E. C. Klein. Program management for the University was provided by Mr. Robert Bertke.

This report covers work conducted for project 3066, task 12, entitled Foreign Object Impact Design Criteria. The contract was sponsored by the Aero Propulsion Laboratory, Air Force Systems Command, Wright-Patterson AFB, Ohio 45433 under the direction of Sandra K. Drake (AFWAL/POTA), Project Engineer.

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SECTION I
INTRODUCTION

The material characterization tests discussed in this report are part of a foreign object damage (FOD) study of jet engine fan blades. The tests constitute a portion of the gross structural damage subtask of that study. The FOD study is designed to provide two resources necessary for the successful development of FOD resistant fan blades: (1) an analysis capability for predicting jet engine response to FOD impacts and (2) an understanding of the mechanisms of FOD failures. The fan blade analytical model uses inputs such as mechanical property data (of the material under consideration) and impact loads (representative of ice balls, ice spears, or small birds) to predict the fan blade response to the foreign object damage impacts. The model allows considerable evaluation of the blade design and material prior to the manufacturing and testing of a full stage of blades. This eliminates many costly experiments that have been necessary in the past.

The material characterization tests provide mechanical properties for use in the blade model discussed above. The materials tested include two metals, 410 stainless steel and 8Al-1Mo-1V titanium (used in the J-79 blade and F-101 blade, respectively) and two composites, boron/2024 aluminum and stainless steel wire mesh (used in the hybrid composite APSI blade). Part A of this report contains the description of the material chracterization tests on the metals. Part B contains the discussion of the material chracterization tests on the composite materials.

The mechanical properties of metals usually exhibit some strain rate dependence.[1,2,3] In addition, experiments have shown that the FOD impacts load various sections of the blades at different rates. For these reasons, tensile tests were conducted on the metals at strain rates ranging from 10^{-3} to

about 10^3 strain/second. The quasi-static and intermediate rate tests (10^{-3} to 1 strain/second), conducted with an MTS closed-loop hydraulic system, provide the following elastic and plastic region parameters: Young's modulus, Poisson's ratio (in the elastic region), 0.2 percent offset yield stress, ultimate stress, and ultimate strain. The dynamic tests (500 to 700 strain/second), conducted on a split-Hopkinson bar apparatus, provide only the plastic region parameters: yield stress, ultimate stress, and ultimate strain. The mechanical properties are summarized in this report as plots of the various parameters versus strain rate.

SECTION II
EXPERIMENTAL PROCEDURES

Tensile tests conducted at the strain rates shown in Table 1 provide the desired mechanical property data. This range of rates encompasses the range of strain rates measured at select locations on the full scale blade tests, 12-370 strain/second. (The full scale blade tests were conducted as part of the gross structural damage subtask IV-A but reported with similar tests in the Task VI report.) The quasi-static and intermediate rate tests (10^{-3} to 1 strain/second) were run on an MTS electro hydraulic closed-loop testing machine. They require different specimens and procedures than do the dynamic tests, which were run on the split-Hopkinson bar apparatus. Consequently, the two types of tests are described separately below.

TABLE 1

STRAIN RATES OF METALLIC MATERIAL CHARACTERIZATION TESTS

Material	Strain Rates (strain/second)
8Al-1Mo-1V Titanium	10^{-3}, 10^{-1}, 1, 500
403 Stainless Steel	10^{-3}, 10^{-1}, 1, 700

2.1 LOW AND INTERMEDIATE STRAIN RATE TESTS

The information obtained from the low and intermediate strain rate tests include two elastic parameters, Young's modulus and Poisson's ratio, and three plastic parameters, the yield stress, the ultimate stress, and the ultimate strain. The following paragraphs describe the specimens used and how they were instrumented and tested. The full true stress-true strain curves appear in Appendix A.

2.1.1 Test Specimen and Specimen Instrumentation

The specimens were made from bar stock which had been worked the same amount as the finished blades. The specimen is illustrated in Figure 1. Its dimensions were per ASTM standard E8-69.[4] Three specimens of each material were tested at each rate with one exception. Only one specimen of the titanium was tested at 1 strain/second.

Figure 2 shows the location of measurement instrumentation placed on the specimens. The extensometer supplied information for obtaining the entire stress-strain from test start to specimen failure. The high resistance foil strain gage placed in the longitudinal direction (the same direction as the applied load) provided high resolution measurements for the parameters in the elastic region and at yield. The strain gage in the transverse direction (to the applied load) supplied measurements for the calculation of Poisson's ratio. The transverse strain gages were applied to only one specimen of each material at each strain rate. The data reduction equations appear in the analysis section of this report.

2.1.2 Test Procedures and Test System

The following paragraphs contain a brief description of the test system and test procedures used for the low and intermediate strain rate tests.

2.1.2.1 Test System

The low and intermediate strain rate tests were conducted using the University's MTS electrohydraulic closed-loop testing system. This closed-loop test machine can be programmed in load, strain, or displacement control. The machine can produce displacement rates that range from less than 0.05 in/min. to 400 in/min. The signal conditioner used with the strain gage was a Honeywell 218 Bridge Amplifier. Included in the test system is an X-Y recorder and a multichannel transient recorder. An additional two pen X-Y recorder was used for these tests.

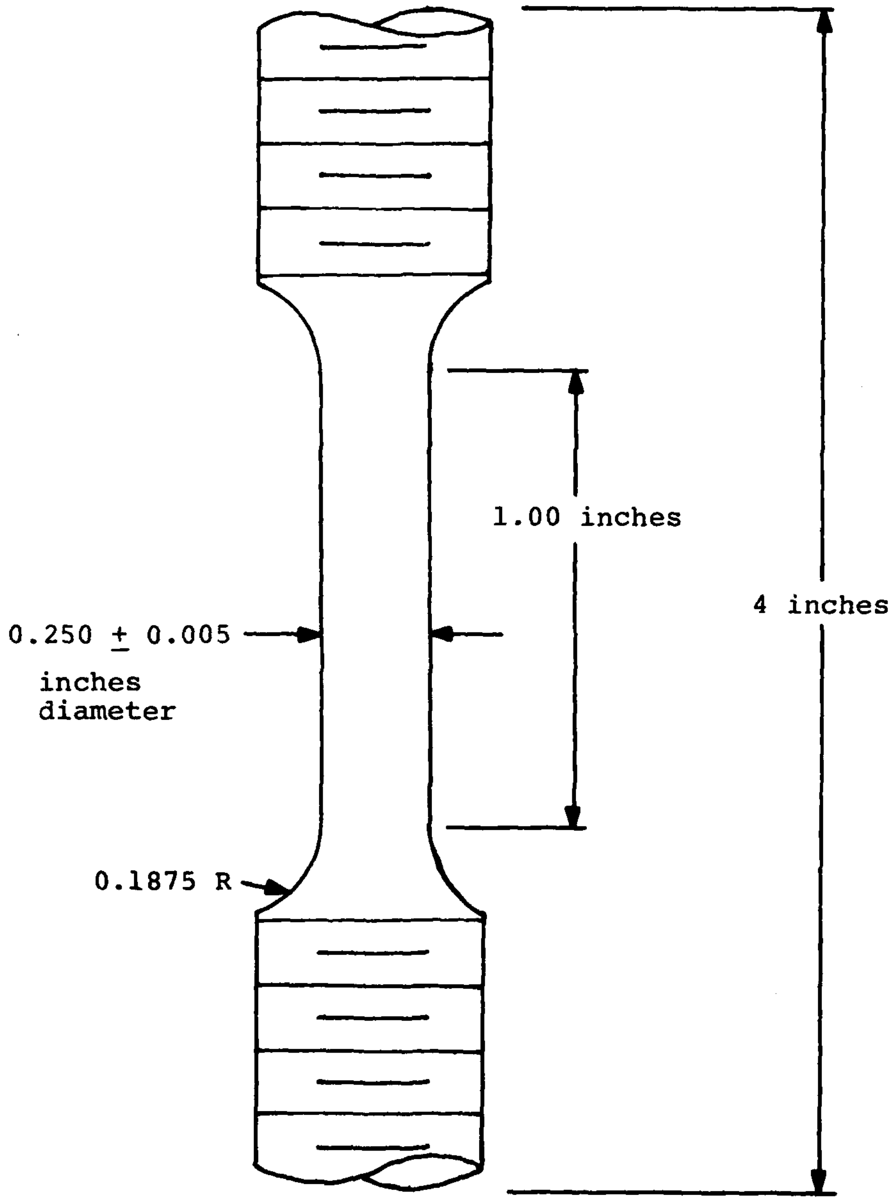


Figure 1. Specimen for Low and Intermediate Strain Rate Tests.

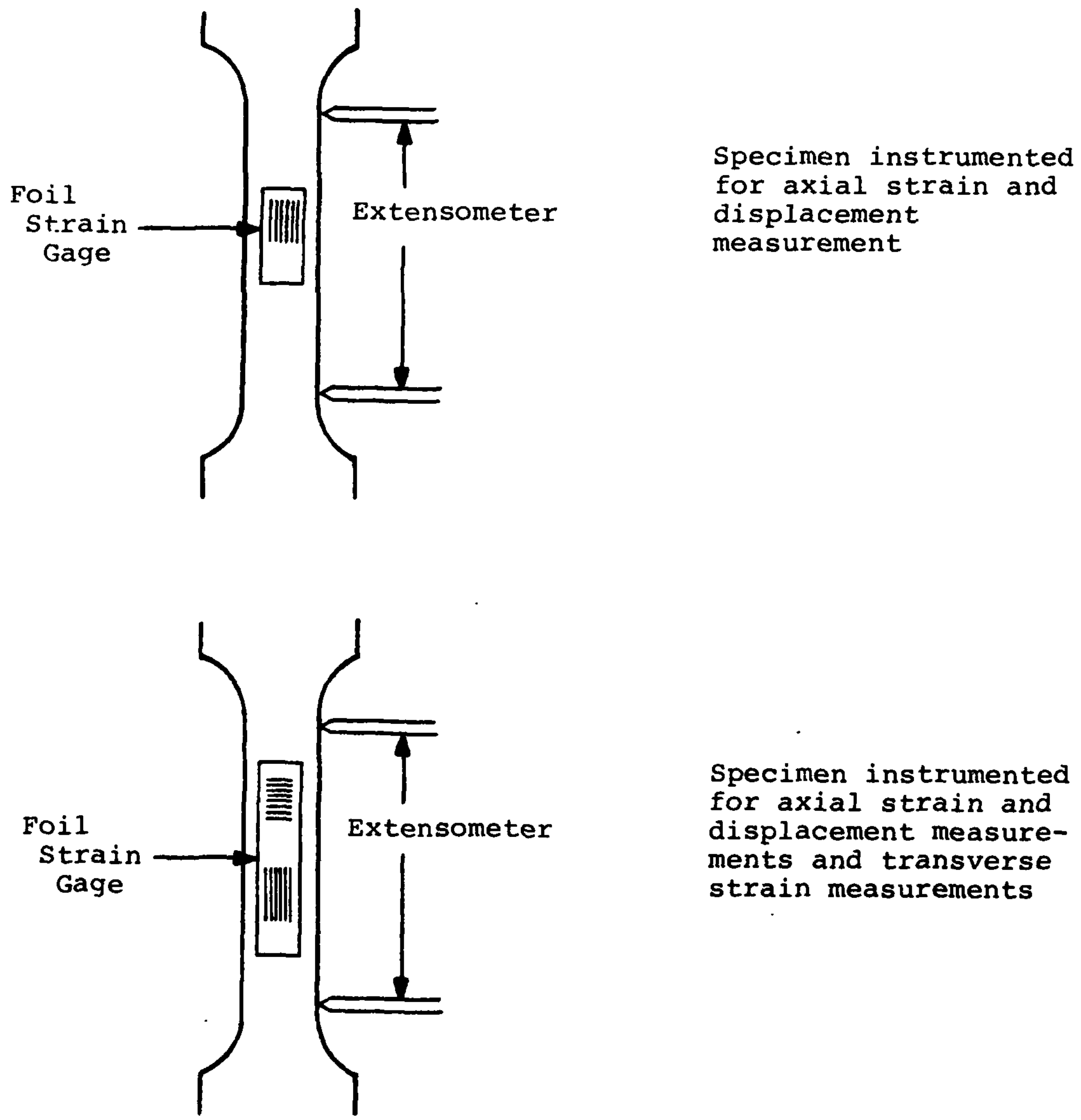


Figure 2. Location of Measurement Instrumentation on the Low and Intermediate Strain Rate Specimens.

2.1.2.2 Test Procedure

After tightening the strain gaged specimen in the grips, the extensometer was attached and adjusted to give the proper output voltage for the desired gage length. With the test machine in the load control mode a linear ramp function loaded the specimen to failure. Load and displacement were recorded directly on the system X-Y recorder for the lowest strain rate tests (10^{-3} strain/second). Load and strain were recorded directly on the additional X-Y recorder. For the higher strain rate tests (10^{-1} and 1 strain/second) the three parameters, load, strain, and displacement were recorded on three channels of the transient recorder for playback at slower speeds into the X-Y recorder.

2.2 HIGH STRAIN RATE TESTS

Mechanical properties obtained from the high strain rate tests include the following three plastic parameters: the yield stress, the ultimate stress, and the ultimate strain. Plastic region true stress-true strain curves were also acquired from the tests. (Elastic properties cannot be obtained from these tests because the pressure waves in the Hopkinson bar are not considered to be in equilibrium in the elastic region). The method (and apparatus) used is the same as that used in a study of the high strain rate tensile mechanical properties study of beryllium.[5] The subsequent paragraphs provide a detailed description of the experimental apparatus, the instrumentation, and the test procedures and mechanisms. The analysis section of this report contains the brief explanation of the data reduction process. The results appear in Appendix B.

2.2.1 Experimental Apparatus

A schematic of the split Hopkinson bar apparatus and the associated instrumentation appears in Figure 3. Three parts of the apparatus are of major interest: two Hopkinson pressure bars (bar No. 1 and bar No. 2) and the striker bar.

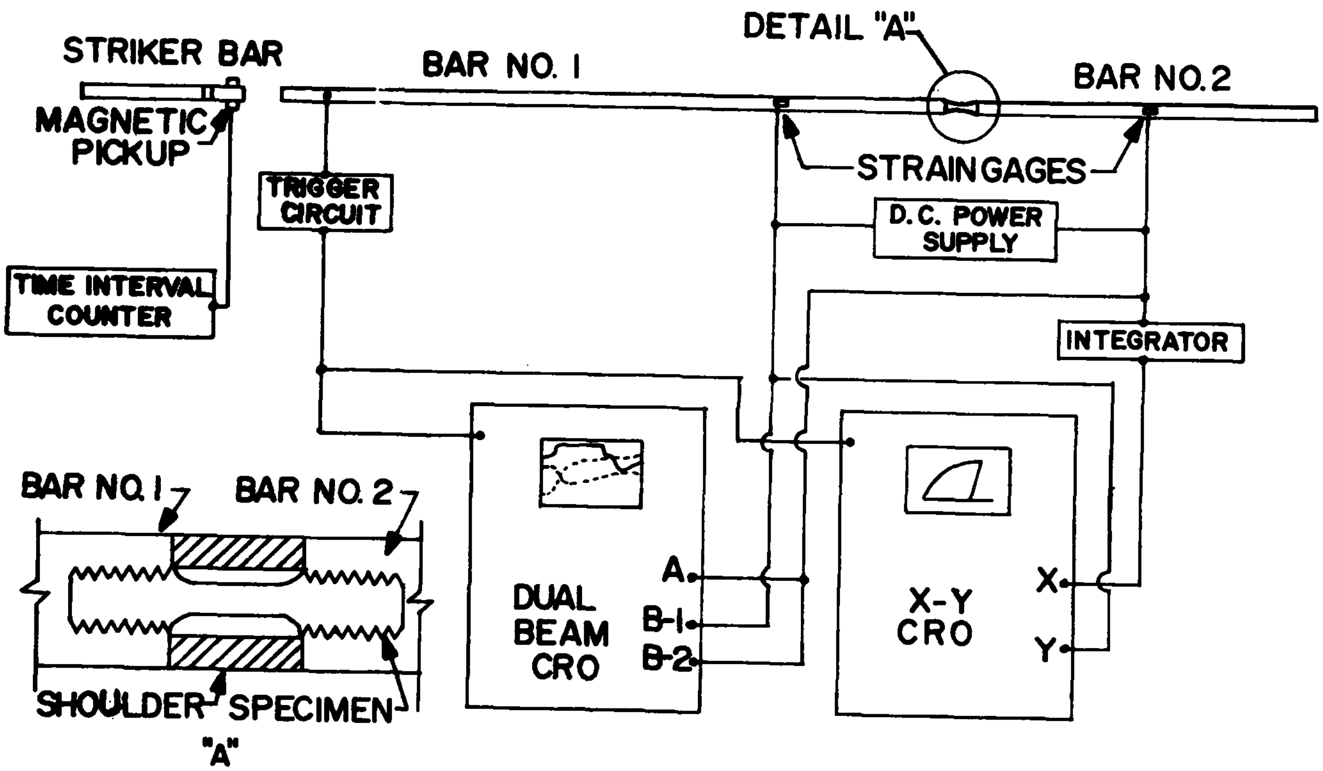


Figure 3. Schematic of Apparatus and Instrumentation for High Strain Rate Tests.

Bar No. 1 must be twice the length of bar No. 2 and the striker bar must be shorter than bar No. 2. For these experiments the bars are 0.06, 0.15, and 0.30 m lengths of 12.7 mm diameter AISI 4130 steel. They are mounted and aligned on a rigid base.

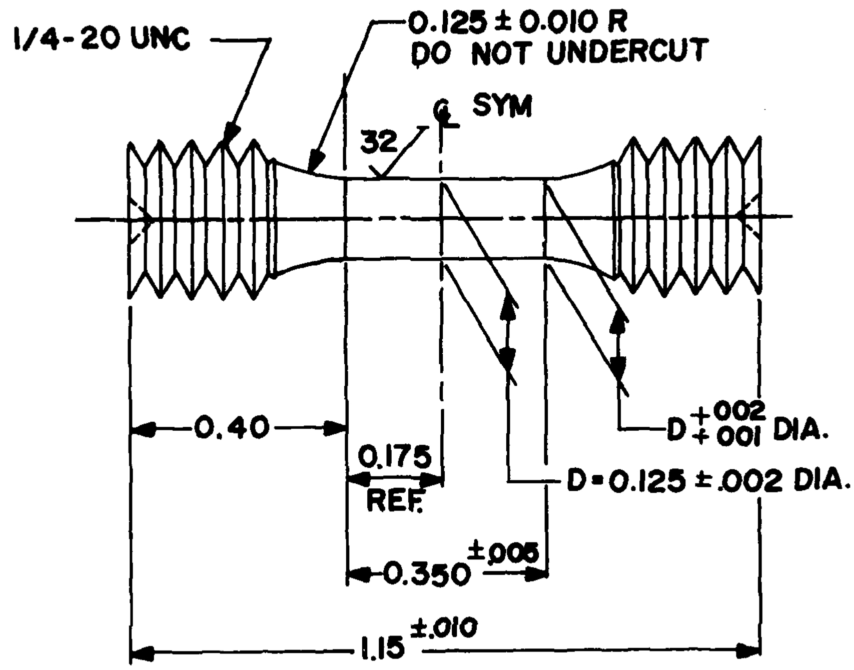
Detail "A" of Figure 3 shows an enlargement of a longitudinal section of the apparatus at the location of the specimen. To prepare for the test, the threaded tensile specimen, shown in Figure 4, is screwed partially into the pressure bars. Then a split shoulder is placed over the specimen, and the specimen is screwed in until the shoulder is snug against the pressure bars. The shoulder has the same outer diameter as the pressure bars (12.7 mm) and it has an inner diameter of 6.4 mm, just large enough to clear the specimen. The shoulder is made of the same material as the pressure bars, AISA 4130 steel. The ratio of the cross-sectional area of the shoulder to that of the pressure bar is 3:4, while the ratio of the area of the shoulder to the net cross-sectional area of the specimen is 12:1.

2.2.2 Instrumentation

The recording circuitry consists primarily of strain gages, two oscilloscopes, and a counter. See Figure 3. The recording system is triggered when the striker bar impacts bar No. 1. A brief review of the major parts of the recording system follows.

Bars No. 1 and 2 are instrumented with high resistance foil strain gages. The gages on eacn bar are placed equidistant from the specimen so that the reflected and transmitted wave signals are time coincident. They are far enough from the specimen that no spurious reflections interfere with the pulses being recorded. Gages are placed diametrically opposite each other on the pressure bars to cancel bending.

The two oscilloscopes record data. One, a dual beam Tektronix type 565 oscilloscope, records the complete



NOTE: ALL DIMENSIONS IN INCHES

THREADED TENSION HOPKINSON BAR SPECIMEN

Figure 4. Specimen for High Strain Rate Tests.

strain time history of the test. One beam records the incident pulse as it passes the first gage. The second beam is used in chopped mode to record both the transmitted pulse (which is proportional to load) and the reflected pulse (which is proportional to strain rate). Figure 5(a) shows a photo of typical traces.

The second oscilloscope, an X-Y Tektronix, records a load-deflection curve. The reflected pulse (from gage No. 2) passes through an electronic integrator and is fed into the X axis of the scope. The signal is proportional to the displacement of the specimen. The signal from gage No. 1, proportional to the load in the specimen, is fed to the Y axis. Figure 5(b) shows the load-deflection trace.

2.2.3 Test Procedures and Mechanisms

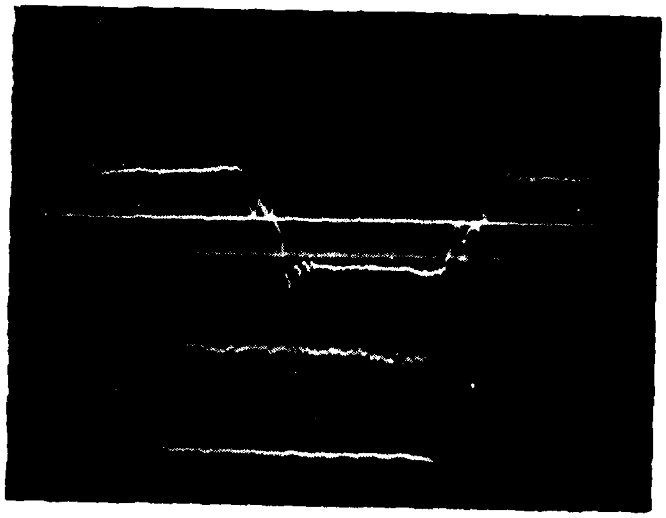
The experiment begins when the striker bar is accelerated so that it impacts bar No. 1. The compression pulse generated travels down bar No. 1 to the specimen-shoulder junction. The pulse passes almost exclusively through the shoulder because of (1) the large area ratio of shoulder to specimen mentioned above and (2) the loose fit of the threaded joints (specimen and pressure bars). The portion of the pulse that passes through the specimen is below the elastic limit of the material. Then the compressive pulse travels through bar No. 2 to the free end, where it reflects as a tensile pulse. When this reflected pulse reaches the specimen, part of it is transmitted through the specimen and part is reflected back into bar No. 2 (because the shoulder doesn't carry the tensile pulse). The incident, transmitted and reflected pulses are recorded and analyzed for the required information.

Figure 6 shows a Lagrangian x-t plot which illustrates the path of the pressure pulse during the test. The amplitude of the incident pressure pulse, generated by the striker bar impacting bar No. 1 is dependent on the striker bar velocity. Its length is twice the longitudinal elastic wave

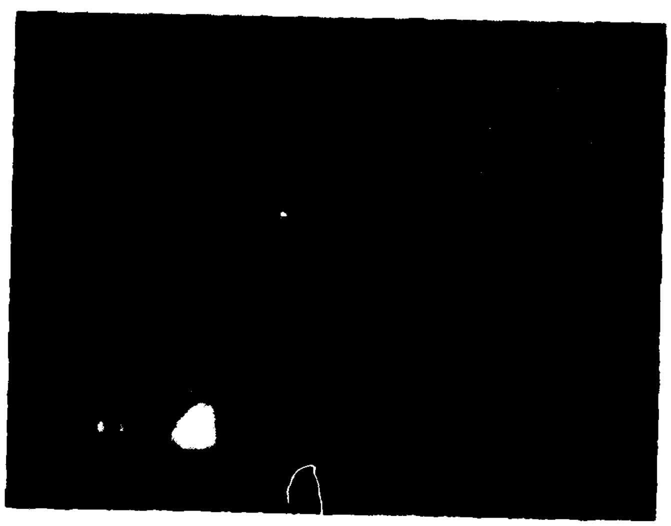
E_i

E_r

E_t



a Specimen: Ti-3



Vert: 465 lb/div.

Horiz:
0.00155 in/div.

b

Figure 5. Typical Oscilloscope Traces.

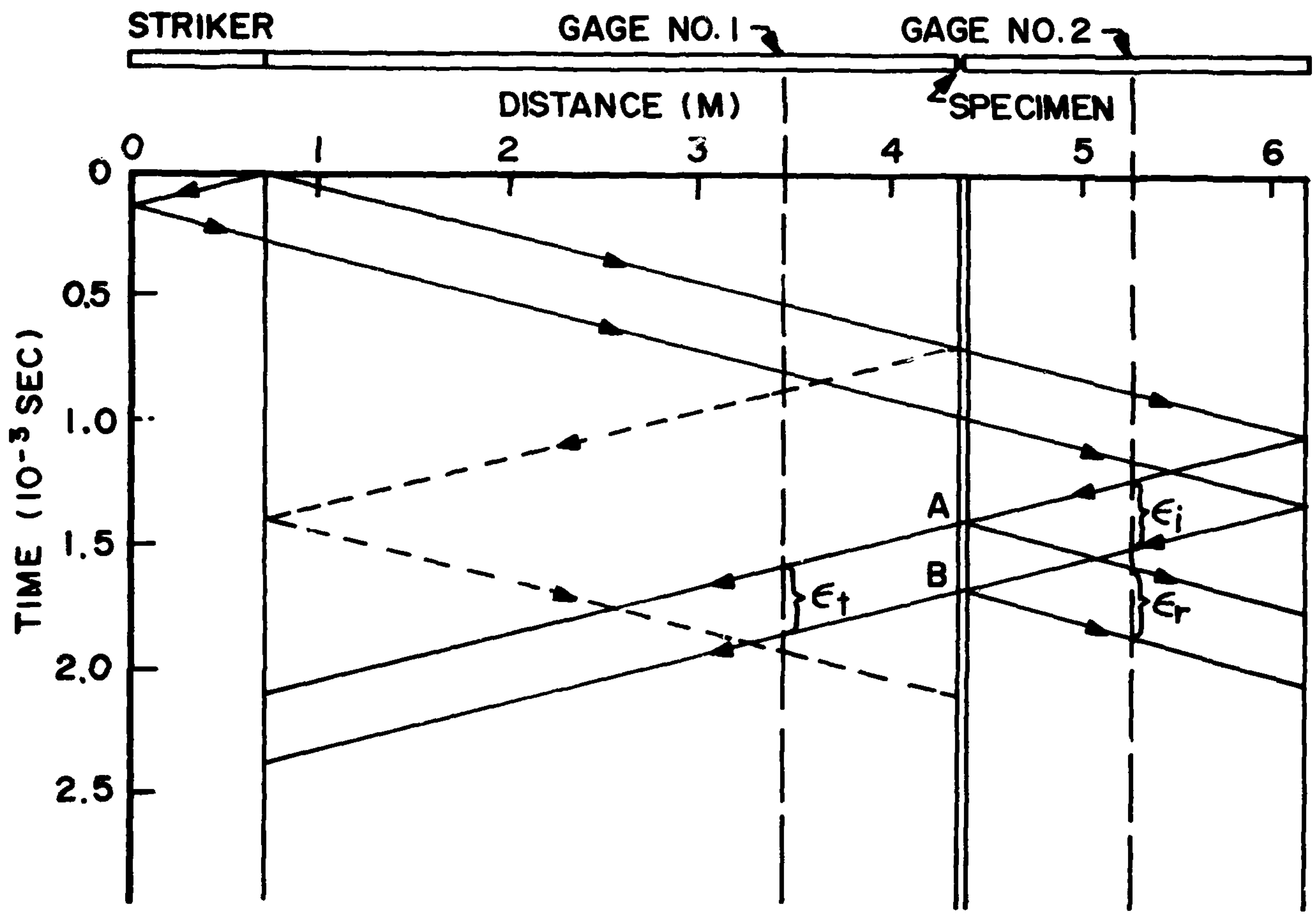


Figure 6. Lagrangian Displacement - Time Plot for High Strain Rate Tests.

transit time in the striker bar. The plot shows that the compressive pulse passes through the entire apparatus and is reflected from the free end of bar No. 2 as a tensile pulse, ε_i. The plot also illustrates the tensile pulse splitting when it reaches the specimen-shoulder junction and part of it, ε_t, being transmitted through the specimen while part, ε_r, is reflected back into bar No. 2.

SECTION III
ANALYSIS

This section outlines the data reduction techniques and equations used to obtain the desired true stress-true strain curves and specific elastic and plastic parameters. All of the test data began as analog load-displacement curves that were then analyzed by various computer routines particular to the test type (low and intermediate, or high strain rate). The results appear in the appendices in analog and digital form.

3.1 LOW AND INTERMEDIATE STRAIN RATE TESTS

The low and intermediate strain rate tests resulted in (1) load-displacement curves from the extensometer and (2) load-strain curves from the strain gages. Converting the displacement measurement to true strain is relatively simple. Using u as displacement and ℓ_o as the initial gage length, one obtains the following:

$$\varepsilon_E = \frac{u}{\ell_o} \quad \text{(engineering strain)} \tag{1}$$

$$\varepsilon_T = \ln\,(1 + \varepsilon_E) \quad \text{(true strain)} \tag{2}$$

where ln is the natural logarithm.

The extensometer gage length, ℓ_o, was 1 inch for these tests. Consequently, the digitized displacement value could be used directly in calculations as engineering strain.

The strain gage data was also simple to reduce. A correction factor was applied to the strain reading to account for the nonlinearity of the bridge circuit. The incremental error, n, is added to the indicated, $\hat{\varepsilon}$, to obtain the actual strain, ε, causing the resistance change in the gage. For this case, a single active gage in a quarter-bridge arrangement, the

correction is

$$n = \frac{F\,(\hat{\varepsilon})^2 \times 10^{-6}}{2 - F\,(\hat{\varepsilon}) \times 10^{-6}} \tag{3}$$

where F is the gage factor. Equation 2 is then used to obtain true strain.

Obtaining true stress values for the low and intermediate strain rate tests is more complicated. True stress, σ_T, is proportional to engineering stress, σ_E, by the ratio of the initial area, A_O, to the current area, A. In the elastic region, where one has small strains, the ratio of areas can be expressed in terms of the longitudinal engineering strain so that

$$\sigma_T = \frac{\sigma_E\,(1 + \varepsilon_E)}{1 + \varepsilon_E\,(1 - 2\nu)} \quad \text{(elastic region true stress)} \tag{4}$$

In the plastic region one assumes the material is incompressible, consequently the volume remains constant. Based on this assumption the true stress in the plastic region becomes

$$\sigma_T = \frac{\sigma_E\,(1 + \varepsilon_E)}{1 + \bar{\varepsilon}_E\,(1 - 2\nu)} \quad \text{(plastic region true stress)} \tag{5}$$

where $\bar{\varepsilon}_E$ is the engineering strain evaluated at the yield point of the material.

Three elastic region parameters were calculated from the strain gage data. Young's modulus is the slope of the linear part of the curve. Poisson's ratio, ν, was obtained for one test per material per strain rate with the following relationship:

$$\nu = +\varepsilon_{transverse}/\varepsilon_{longitudinal}$$

The shear modulus, G, was calculated with the equation

$$G = \frac{E}{2\ (1 + \nu)}$$

The values of these mechanical properties appear in the results section. An additional parameter, the yield stress, was obtained from these curves. It was evaluated using the 0.2 percent (strain) offset method because neither of the metals exhibits a definite yield point. The load-displacement curves were analyzed using Equations 2,4, and 5 to produce the full true stress-time strain curves. The ultimate strain was taken as the final strain value of the curve. However, the ultimate stress was calculated using the final load divided by the final reduced area of the specimens because Equation 5 is not accurate (complete) for large amounts of plasticity.

These curves were all digitized on the University of Dayton's Tektronix 4014-1 computer graphics terminal and associated digitizing board.

3.2 HIGH STRAIN RATE TESTS

The polaroid photographs of the load-deflection traces obtained from the high strain rate tests were digitized using a Hewlett Packard 9800 series calculator and digitizer (located at the AFML) to produce true stress-engineering strain curves. Those curves were then digitized on the Tektronix 4014-1 computer graphics terminal and digitizing board (located at the University) to produce true stress-true strain curves. A brief review of the analysis in the two data reduction programs follows. Details of the theory of the measurements appear in documents by U. S. Lindholm[6] and by Lindholm and L. M. Yeakley.[7]

The average stress in the specimen is:

$$\sigma_s = E\ (A/A_s)\ \varepsilon_t \qquad (6)$$

where E and A are the elastic modulus and cross-sectional area of the pressure bars, A_s is the cross-sectional area of the specimen and ε_t is the transmitted wave. Using the assumption of no volume change after first yield, Equation (6) is modified to:

$$\sigma_T = E(A/A_s)\ \varepsilon_t \frac{1}{(1 + \varepsilon_t)} \qquad (7)$$

for true stress.

Engineering strain was obtained from the deflection values using the following relationship:

$$\varepsilon = 0.265\ \delta - 0.5\ (1 - \exp^{-0.55\ \delta})$$

where ε represents strain in percent and δ represents the deflection in mils between the grips.[5] This equation results from least-squares fitting many deflection-strain plots from several different materials. It is particular to the specimen size used, not to a material.

The yield stress was determined as the point on the stress-strain curve at which the increase in applied load essentially ceased. The ultimate stress and ultimate strain were selected as the final point on the stress-strain curve. Reasons for this selection procedure appear in the results and discussion section.

SECTION IV
RESULTS AND DISCUSSION

The mechanical properties acquired from the various strain rate tests on 8Al-1Mo-1V titanium and 410 stainless steel appear in Tables 2 and 3, respectively. Table 4 shows the measured density of each material. Figures 7 through 10 are plots of the mechanical properties versus strain rate. The points lacking standard deviation marks either represent one data point or they represent averaged data having a standard deviation smaller than the data symbol. The true stress-true strain curves for the low and intermediate tests (Appendix A) have two parts to the curve in the plastic region. The solid line represents the test data analyzed with the plastic region equations given in the analysis section. Obviously these are not complete for large strains. The dotted line joins the ultimate stress (calculated with the final load and reduced cross-sectional area)-ultimate strain point to the test curve.

Studying Figures 7 through 10, one concludes that all of the tensile mechanical properties determined by these tests vary with strain rate with the exception of the elastic modulus of titanium. Perhaps additional testing of the stainless steel would reveal that its elastic modulus also does not vary with strain rate. It is important to consider the comments in the following paragraphs when using the curves shown as data for calculations.

A very small specimen must be used for high strain rate tests to satisfy assumptions made in the Hopkinson bar theory equations. This presents problems in obtaining accurate data from the tests, particularly in the elastic region. One problem is that achievable machining tolerances on the specimen in relation to load surface alignment make it difficult to resolve small strains accurately. Secondly, an assumption made in developing the Hopkinson bar equations is that many stress

TABLE 2

MECHANICAL PROPERTIES OBTAINED FOR 8Al-1Mo-1V TITANIUM

Specimen	Strain Rate (ε/sec)	Elastic Modulus (x 10^6 psi)	Shear Modulus (x 10^6 psi)	Yield Stress (ksi)	Ultimate Stress (ksi)	Ultimate Strain (percent)
1-Ti	0.001	16.9	6.5	148.9	202.5	28.2
2-Ti	0.001	17.3	6.7	148.7	200.8	27.2
3-Ti	0.001	17.4	6.8	148.7	199.3	21.8
4-Ti	0.10	15.8	6.3	156.3	188.5	13.7
5-Ti	0.10	16.9	6.8	153.0	189.1	15.9
6-Ti	0.10	17.1	6.8	156.4	194.5	15.3
7-Ti	1.0	17.3	6.8	164.0	184.6	15.7
Ti-3	550	*	*	203.0	161.1	13.7
Ti-2	560	*	*	202.0	154.2	14.5
Ti-1	580	*	*	208.0	158.7	15.3

Poisson's Ratio = 0.279

* Elastic properties are not obtainable from the high strain rate tests.

TABLE 3

MECHANICAL PROPERTIES OBTAINED FOR 410 STAINLESS STEEL

Specimen	Strain Rate (ε/sec)	Elastic Modulus (x 10^6 psi)	Shear Modulus (x 10^6 psi)	Yield Stress (ksi)	Ultimate Stress (ksi)	Ultimate Strain (percent)
4-SS	0.001	27.4	10.6	84.2	207.2	26.7
5-SS	0.001	30.5	11.7	84.8	207.2	27.2
6-SS	0.001	33.7	12.9	84.9	211.9	26.9
9-SS	0.10	27.7	11.2	87.2	191.9	25.7
10-SS	0.10	26.4	10.2	87.0	188.3	26.8
11-SS	0.10	28.2	10.9	89.2	198.3	23.5
12-SS	1.0	27.2	10.4	86.6	182.7	23.8
13-SS	1.0	26.1	10.0	91.3	185.5	25.4
14-SS	1.0	27.2	10.4	94.5	183.8	24.6
15-SS	1.0	28.0	10.9	88.8	184.7	25.6
SS-5	680.0	*	*	124.0	129.5	16.9
SS-4	760.0	*	*	123.0	130.0	17.2
SS-3	700.0	*	*	131.0	131.4	18.0
SS-2	530.0	*	*	128.0	**	**
SS-1	340.0	*	*	126.0	**	**

Poisson's Ratio = 0.297

* Elastic properties are not obtainable from the high strain rate tests.

** These specimens did not fail.

TABLE 4

DENSITY

Material	Density
8Al-1Mo-1V Titanium	4.32 g/cm^3
410 Stainless Steel	7.57 gm/cm^3

wave reflections occur in the specimen before a state of dynamic equilibrium exists. This does not happen until some plastic deformation has taken place. In addition, once necking occurs in the specimen a uniform stress field no longer exists making the equations for stress and strain invalid. This is a significant factor for the small specimens.

However, the split-Hopkinson bar apparatus represents the state-of-the-art technique for obtaining stress-strain information at high strain rates. The curves are considered most accurate in the range of 2 to 10 percent strain. The yield stress values reported represent the point on the curves where the load ceases to increase significantly for a rather large increase in displacement. (The 0.2 percent offset method obviously cannot be used because of the lack of data in the elastic region.) The ultimate stress and ultimate strain values from these tests were the final point of the curve. Although the values from the high strain rate tests cannot be used as exact data points they are useful in establishing the trend of the strain rate dependence of the subject materials over nearly seven decades of strain rate.

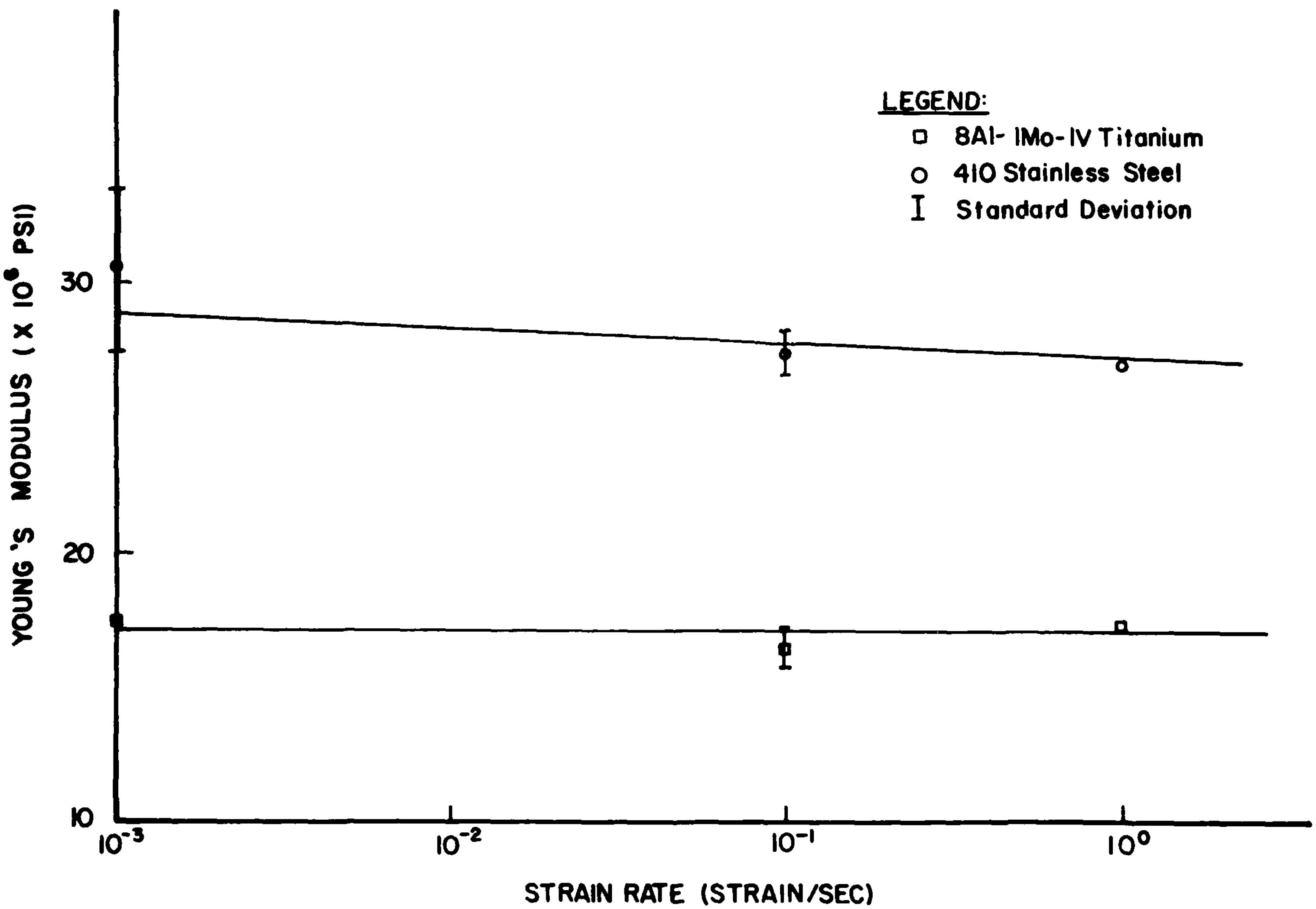


Figure 7. Young's Modulus VS. Strain Rate.

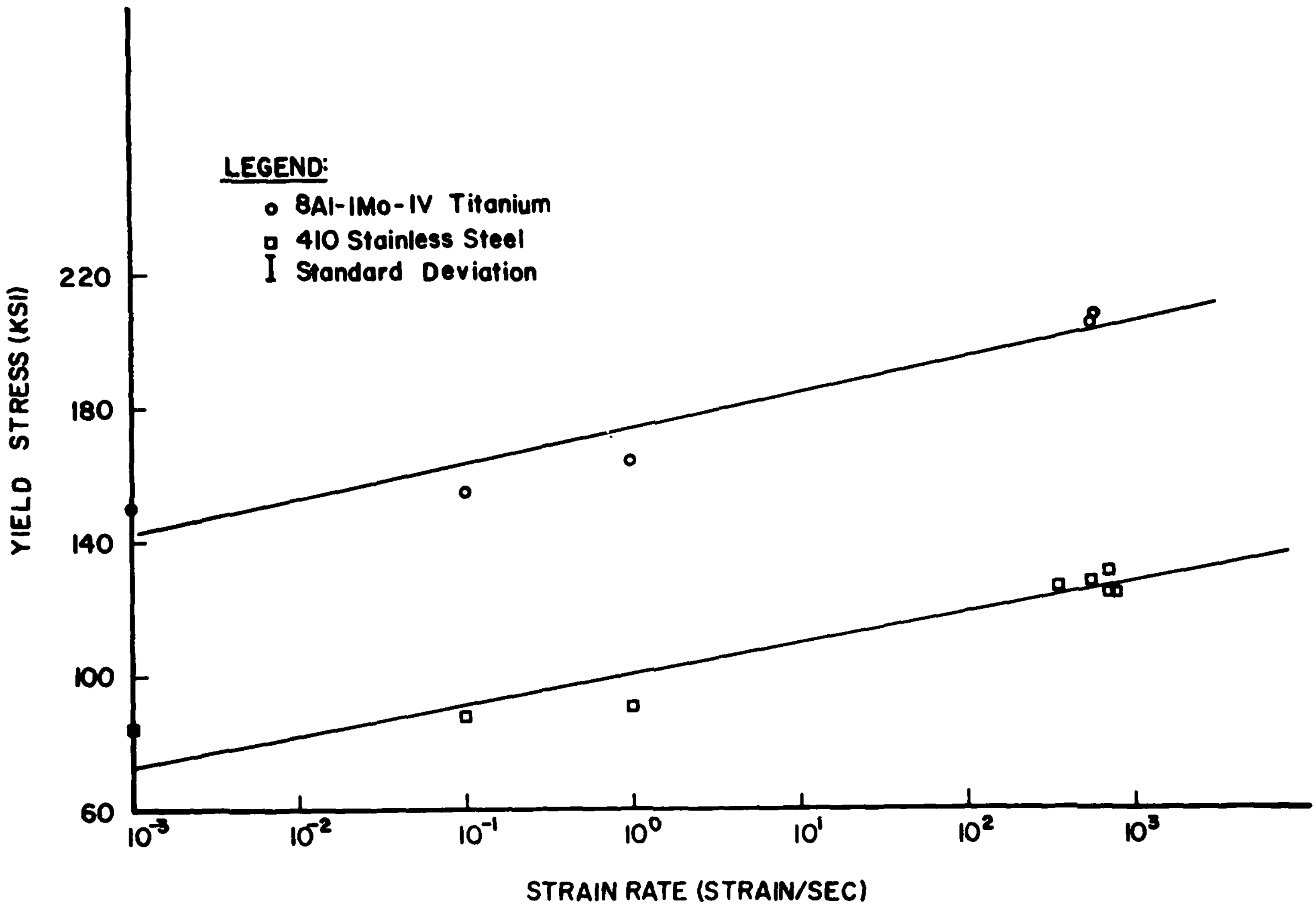


Figure 8. Yield Stress VS. Strain Rate

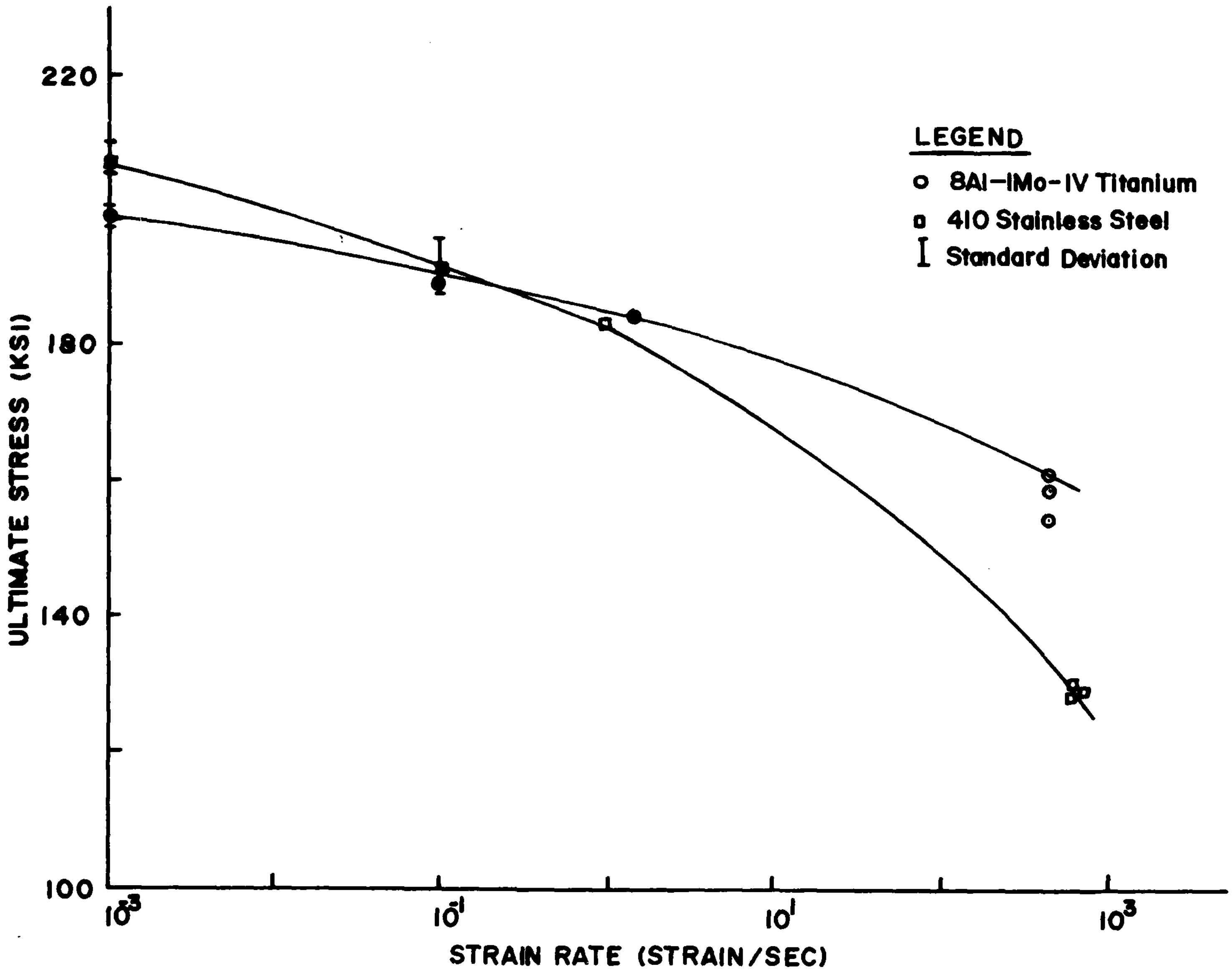


Figure 9. Ultimate Stress VS. Strain Rate.

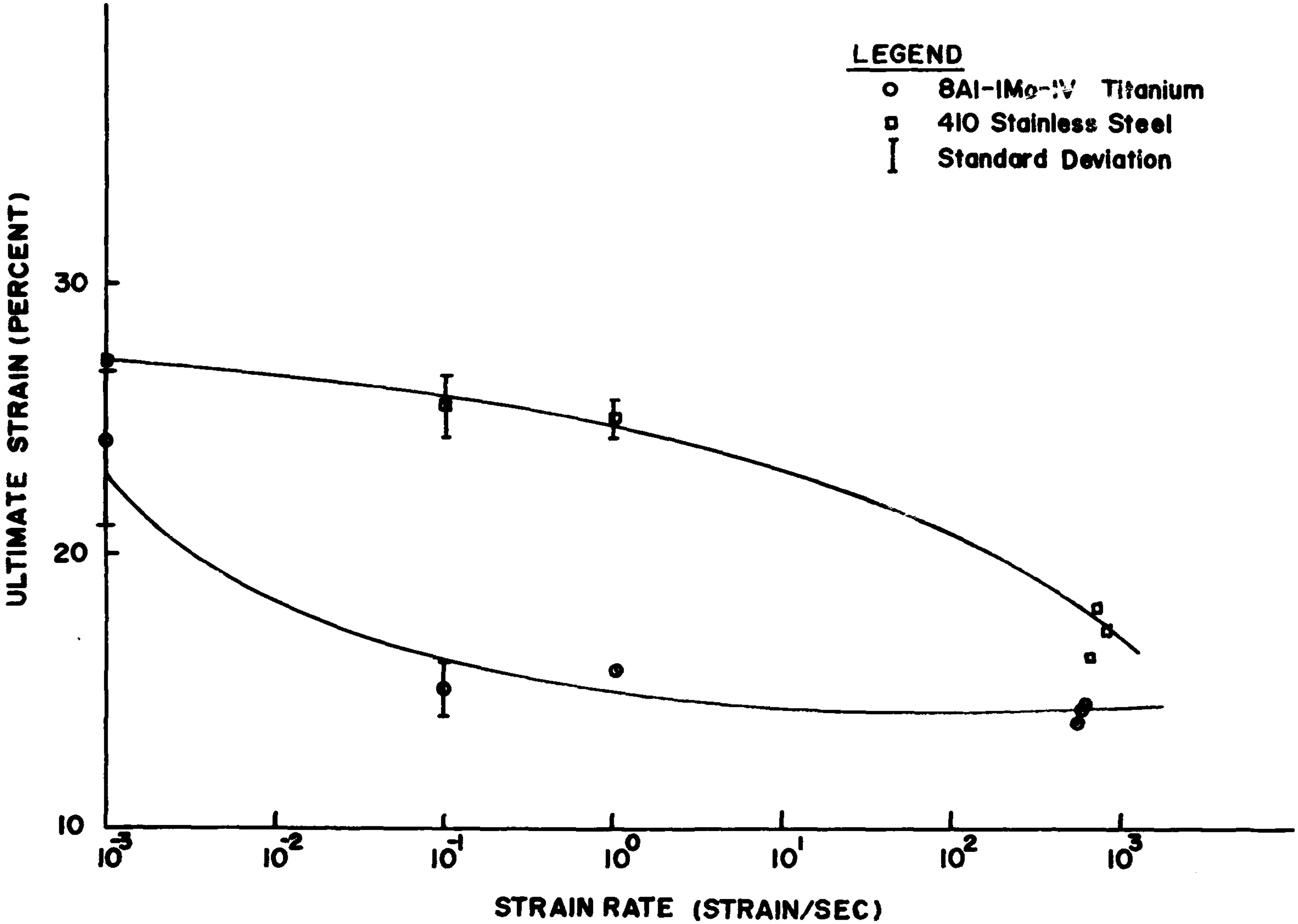


Figure 10. Ultimate Strain VS. Strain Rate.

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2. Green, S.J. and S.G. Babcock, "Response of Materials to Suddenly Applied Stress Loads: Part I: High Strain-rate Properties of Eleven Reentry-vehicle Materials at Elevated Temperatures," TR66-83 Part I, November 1966.

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4. 1977 Annual Book of American Society for Testing and Materials Standards, Part 10: Metals Physical, Mechanical, Corrosion Testing, pp. 154-173.

5. Nicholas, T., "Mechanical Properties of Structural Grades of Beryllium at High Strain Rates," AFML-TR-75-168, October 1975.

6. Lindholm, U.S., "Some Experiments with the Split Hopkinson Pressure Bar," Journal of the Mechanics and Physics of Solids, 1964, Vol. 12, pp. 317-335.

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APPENDIX A

LOW AND INTERMEDIATE STRAIN RATE CURVES AND DIGITAL DATA

STANDARD TENSILE
0.001 STRAIN/SEC
8AL-1MO-1V TITANIUM
SPEC 1-TI

1	.05808615	7.606
2	.13095612	18.700
3	.19177013	29.176
4	.25309949	38.436
5	.31774354	49.340
6	.39414203	61.289
7	.45869500	72.210
8	.51532190	82.512
9	.58442456	92.229
10	.66006961	105.440
11	.72509252	114.962
12	.79313489	126.747
13	.86556287	137.730
14	.92657194	146.856
15	1.00219249	150.487
16	1.11203352	150.089
17	1.24605928	149.756
18	1.39590318	149.741
19	1.60598576	150.503
20	1.79960876	150.811
21	1.98463584	151.511
22	2.16923089	152.419
23	2.31751753	153.025
24	2.51358850	153.762
25	2.69730043	154.468
26	2.91653145	155.274
27	3.32579162	156.814
28	3.54778703	157.218
29	3.70994237	157.667
30	3.85999825	158.083
31	4.03346633	158.567
32	4.21056616	159.062
33	4.44237782	159.500
34	4.63441857	160.041
35	4.81054619	160.325
36	4.98636415	160.610
37	5.16559302	161.332
38	5.34476368	161.416
39	5.51947106	162.129
40	5.62437597	162.000
41	5.76375881	162.615
42	18.36507948	184.912
43	19.06724825	186.435
44	19.85094865	188.399
45	20.42284516	189.168
46	20.80217157	189.761
47	21.35157297	190.485
48	21.89758980	191.457
49	22.35680507	191.733
50	22.91458814	192.485
51	23.52098873	192.326
52	23.97357551	192.067
53	24.50736323	191.729
54	25.02294920	190.561
55	25.51986117	189.072
56	26.03136782	187.072
57	26.36044937	185.434
58	26.80294393	183.240
59	27.21124511	180.949
60	27.55362870	178.494
61	27.71636055	177.242
62	27.92866958	174.751
63	28.09151205	172.950
64	28.23705382	171.913

STANDARD TENSILE
0.001 STRAIN/SEC
8AL-1MO-1V TITANIUM
SPEC 2-TI

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2	.06393684	10.304
3	.13626456	20.631
4	.19605711	30.739
5	.26735502	42.304
6	.36057480	58.211
7	.41306960	66.695
8	.46522603	75.591
9	.52186549	84.093
10	.58173847	93.835
11	.63023282	101.921
12	.68336169	109.409
13	.73925781	118.749
14	.81140866	128.750
15	.87203732	137.296
16	.92116468	144.385
17	.97227816	148.820
18	1.03806357	150.428
19	1.10983378	149.593
20	1.20642624	149.061
21	1.36910988	149.394
22	1.52336818	149.495
23	1.70183256	150.296
24	1.88857076	150.713
25	2.20703259	151.784
26	2.37588535	152.769
27	2.54064246	153.328
28	2.70497660	154.096
29	2.92250511	154.840
30	3.11940727	155.098
31	3.26630093	156.023
32	3.41766243	156.127
33	3.55612205	156.817
34	3.72316532	157.188
35	3.88571937	157.755
36	4.04425547	157.887
37	4.17390316	158.342
38	4.35982825	159.208
39	4.49355161	159.044
40	4.65903757	159.417
41	4.79191517	159.888

42	4.93667146	160.403
43	5.07349043	160.465
44	5.23000791	160.810
45	5.36627842	161.085
46	5.49437230	161.330
47	5.59835558	161.490
48	5.72201868	161.936
49	5.76194818	161.937
50	5.79390030	161.980
51	5.89757274	162.140
52	17.39831956	182.551
53	17.91841989	183.520
54	18.52399766	184.941
55	19.23438722	185.642
56	19.65989960	185.420
57	20.12050715	184.534
58	20.49262849	183.179
59	20.84923062	180.527
60	21.16870509	178.270
61	21.45459210	175.166
62	21.66894962	172.637
63	21.86567641	170.057
64	22.06201694	167.465
65	22.18952346	164.712

STANDARD TENSILE
0.001 STRAIN/SEC
8AL-1MO-1V TITANIUM
SPEC 3-TI

1	.03517916	6.201
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3	.21852306	37.670
4	.34086947	60.050
5	.45347408	79.364
6	.52745918	91.841
7	.63651008	110.366
8	.71354925	123.903
9	.78369924	135.995
10	.83377775	143.114
11	.89611551	149.655
12	.97433101	150.698
13	1.10122772	149.826
14	1.27510783	149.150
15	1.46768503	149.414
16	1.77660145	150.918
17	1.95216175	151.749
18	2.15077819	152.666
19	2.34541437	153.156
20	2.50073147	153.714
21	2.79874148	155.209
22	2.99984327	155.732
23	3.16185702	156.323
24	3.32775315	156.510
25	3.47386876	157.047
26	3.60457084	157.317
27	3.71195815	157.714
28	3.82703562	157.928
29	3.97227681	158.678
30	16.22844144	180.173

31	16.59235611	181.254
32	17.06298561	182.832
33	17.55082489	183.978
34	18.23478545	185.110
35	18.86348576	185.137
36	19.23840786	185.293
37	19.68592785	184.385
38	20.09767138	182.884
39	20.36898645	180.538
40	20.71079176	177.843
41	21.05277328	174.627
42	21.26942783	172.109
43	21.43361443	169.461
44	21.68670513	165.992
45	21.79839834	163.207

STANDARD TENSILE
0.001 STRAIN/SEC
410 STAINLESS STEEL
SPEC 4-SS

1	.01040279	3.260
2	.02052039	7.131
3	.03824873	11.718
4	.05214512	15.998
5	.06627623	19.771
6	.08049998	23.340
7	.10195010	28.441
8	.11238959	31.603
9	.11876524	34.967
10	.13340720	37.622
11	.14766870	41.093
12	.16551635	45.381
13	.18350264	49.365
14	.19780426	52.736
15	.20780840	56.818
16	.22616511	59.988
17	.25937818	65.310
18	.28942161	68.899
19	.31177121	71.974
20	.34971736	75.571
21	.39575265	78.768
22	.44605215	81.255
23	.51209110	83.859
24	.59021838	85.887
25	.72337912	88.293
26	.85664452	90.091
27	.99390076	91.386
28	1.18604306	92.546
29	1.39764138	93.220
30	1.62419687	94.432
31	1.80760887	94.973
32	2.04130257	95.580
33	2.26289254	95.967
34	2.46839706	96.542
35	2.67348013	97.119
36	2.92454747	97.549
37	3.19427399	97.900
38	3.39024036	98.366
39	3.58591483	98.623

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45    4.85035264    100.512
46    4.97895455    100.685
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53   14.02848708    111.198
54   14.63027639    111.820
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56   15.62951275    112.703
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59   16.76333720    113.282
60   17.11053232    113.477
61   17.38495616    113.701
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63   18.01485193    113.888
64   18.32234909    114.033
65   18.40532138    113.771
66   22.4866069     113.714
67   22.87603031    112.023
68   23.36579787    109.282
69   23.73560876    107.275
70   24.08849560    104.586
71   24.49019167    101.542
72   24.84140932     98.157
73   25.15865730     94.711
74   25.50890054     90.359
75   25.74152234     87.570
76   25.97413504     84.373
77   26.19025726     81.014
78   26.38861546     78.417
79   26.53849205     75.504
80   26.70388309     72.860
81   26.83546185     71.109
82   26.90233717     69.436
STANDARD TENSILE
0.001 STRAIN/SEC
410 STAINLESS STEEL
SPEC 5-SS
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 2     .02540123      8.352
 3     .03776667     10.695
 4     .04217158     13.038
 5     .04672419     16.197
 6     .06334312     20.069
 7     .06809804     24.350
 8     .07668326     27.815
 9     .10178791     34.646
10     .12646144     39.134
11     .13914681     43.316
12     .15589810     48.009
13     .17658406     52.500
14     .19726574     56.991
15     .21397040     61.483
16     .23867162     66.284
17     .27928581     71.295
18     .31165099     74.673
19     .36002250     78.875
20     .43995758     82.375
21     .51966323     84.959
22     .62694926     87.288
23     .76567796     89.339
24     .90803160     90.680
25    1.08169585     92.050
26    1.29826164     93.253
27    1.56525307     94.089
28    1.76896874     94.877
29    2.01512792     95.288
30    2.27632310     96.129
31    2.46687236     96.497
32    2.65318220     96.862
33    2.84686707     97.130
34    3.06724456     97.631
35    3.23702333     97.986
36    3.39881806     98.334
37    3.59876485     98.716
38    3.77144280     98.865
39    3.88260193     99.172
40    3.95528677     98.917
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44   18.17075977    115.655
45   18.71788981    115.904
46   19.54194813    116.589
47   20.22035414    116.738
48   20.75633392    116.847
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50   22.14247383    115.639
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52   23.07143095    112.461
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54   23.87460523    108.692
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60   26.12703423     88.642
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63   26.75751247     80.013
64   27.07880156     74.660
65   27.19091162     72.605
66   27.31920534     70.823
67   27.30289613     70.545
STANDARD TENSILE
0.001 STRAIN/SEC
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410 STAINLESS STEEL
SPEC 6-SS

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5	.02675336	14.854
6	.04102432	19.941
7	.05491508	24.214
8	.08136758	29.912
9	.10441394	36.835
10	.11867382	41.926
11	.14142820	48.240
12	.16790505	54.047
13	.19017616	59.346
14	.21201755	63.729
15	.24583095	68.318
16	.28349775	72.705
17	.31657978	75.768
18	.38972589	79.961
19	.46629966	83.138
20	.54243852	85.513
21	.62626980	87.603
22	.70590070	89.284
23	.73757569	89.610
24	.86417541	90.914
25	1.01812953	92.237
26	1.22289352	93.699
27	1.48546666	94.172
28	1.75914905	94.861
29	1.99720336	95.841
30	2.21120910	96.393
31	2.39365903	96.719
32	2.68037895	97.531
33	2.86583389	97.861
34	3.02398480	98.174
35	3.24344844	98.633
36	3.44311656	98.765
37	3.66927254	99.125
38	3.79931531	99.212
39	3.97503224	99.434
40	4.15048632	99.762
41	4.27619180	100.058
42	4.39414048	100.349
43	4.43977093	100.486
44	16.95228513	114.734
45	17.53303671	115.354
46	18.23269361	116.228
47	18.87494346	116.678
48	19.54729098	117.037
49	20.31678132	117.003
50	20.84361732	117.075
51	21.48523133	116.890
52	21.93722072	115.861
53	22.53591744	113.958
54	22.94936018	112.476
55	23.47494230	109.809
56	23.85001812	107.222
57	24.32113873	104.057
58	24.56268379	101.559
59	24.93235050	97.990
60	25.25290308	95.005
61	25.61848933	90.331
62	25.88805782	86.996
63	26.09287394	83.859
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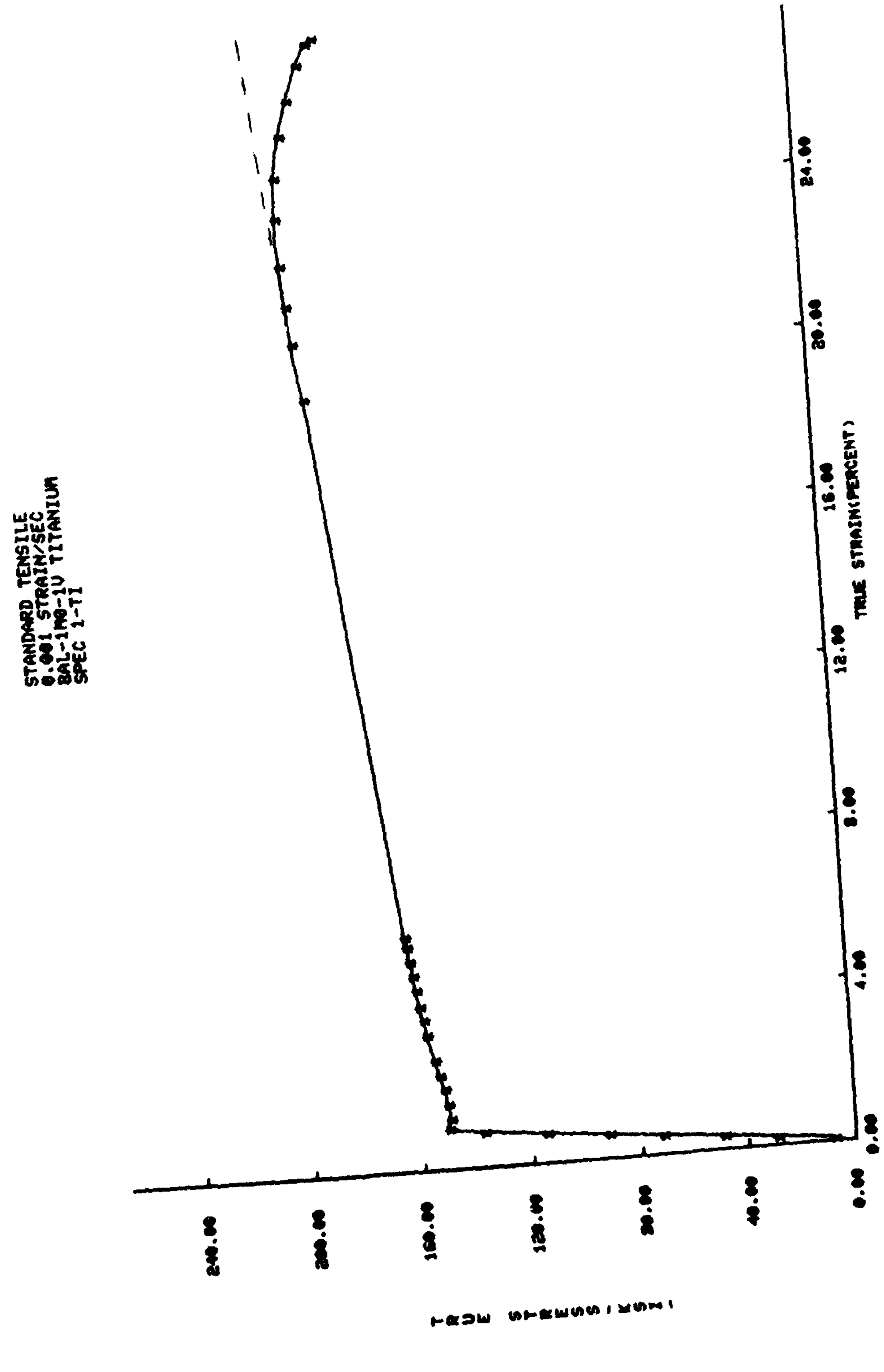
67	26.87562877	70.886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8AL-1MO-1V TITANIUM
SPEC 1-TI
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12.00
16.00
20.00
24.00
TRUE STRESS(KSI)
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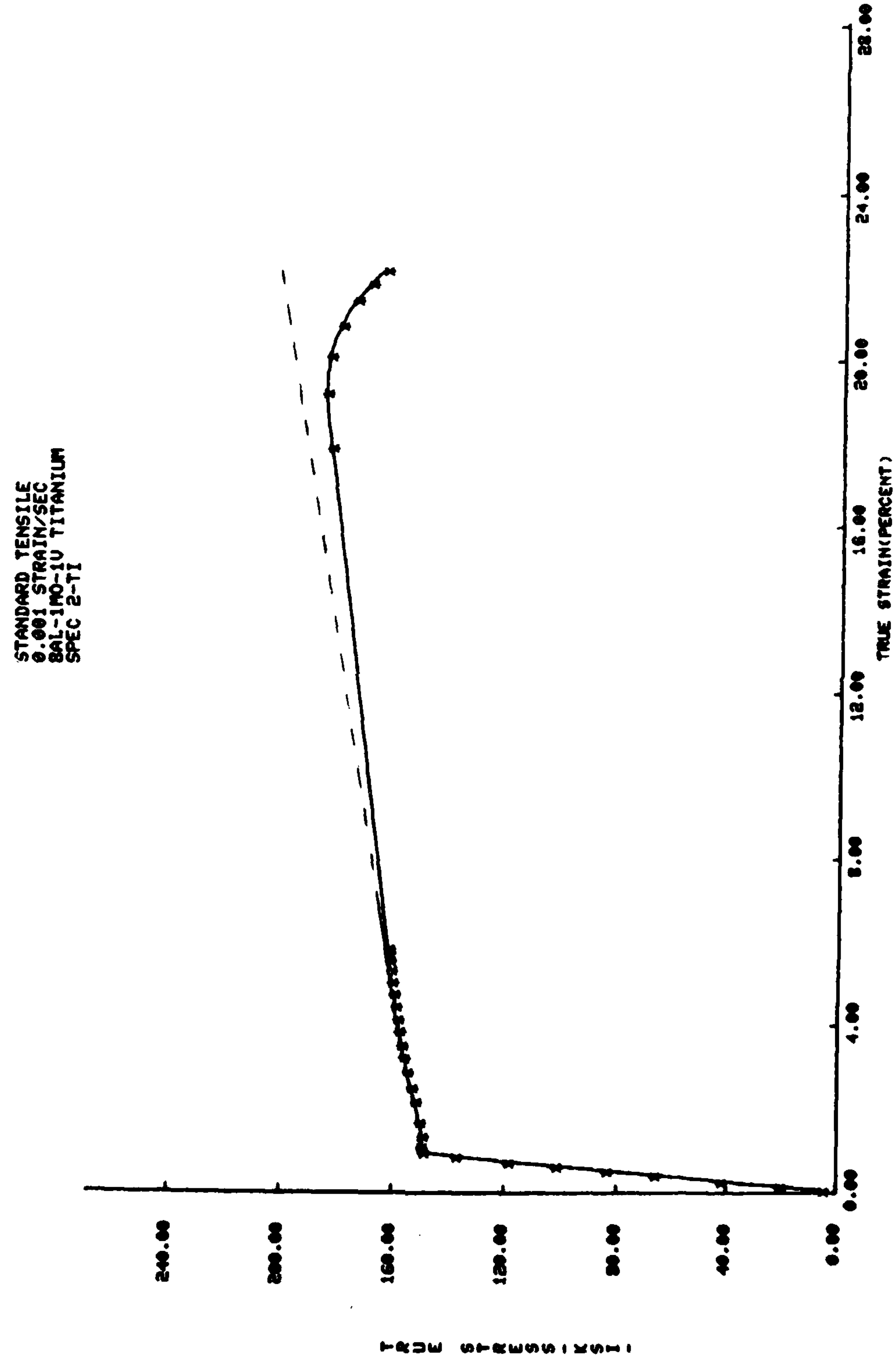
40.00
80.00
120.00
160.00
200.00
240.00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SPEC 2-TI
TRUE STRESS(KSI)
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80.00
120.00
160.00
200.00
240.00
TRUE STRAIN(PERCENT)
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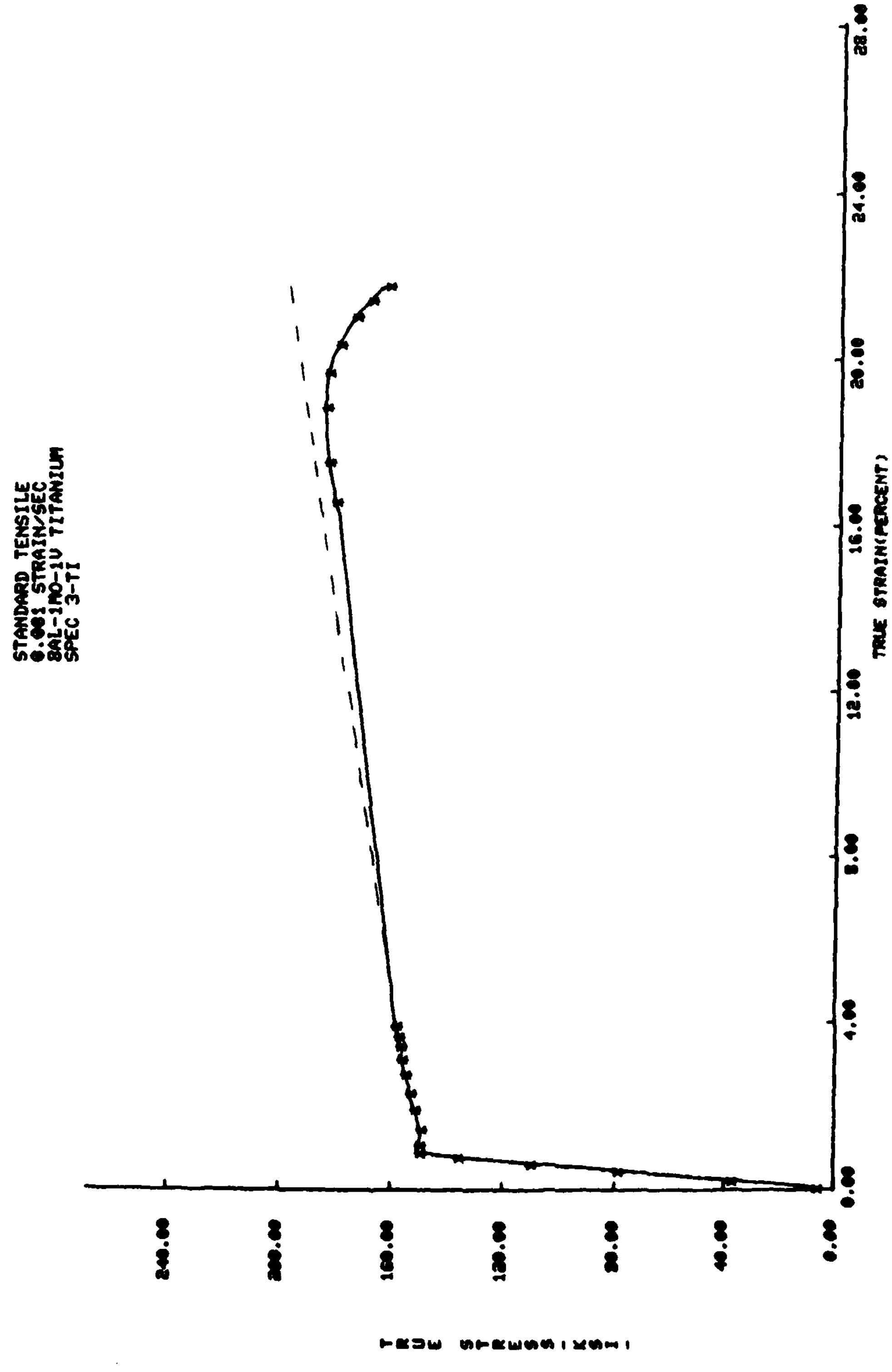
8.00
12.00
16.00
20.00
24.00
28.00


STANDARD TENSILE
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8AL-1MO-1V TITANIUM
SPEC 3-TI
TRUE STRAIN(PERCENT)
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8.00
12.00
16.00
20.00
24.00
28.00
TRUE STRESS(KSI)
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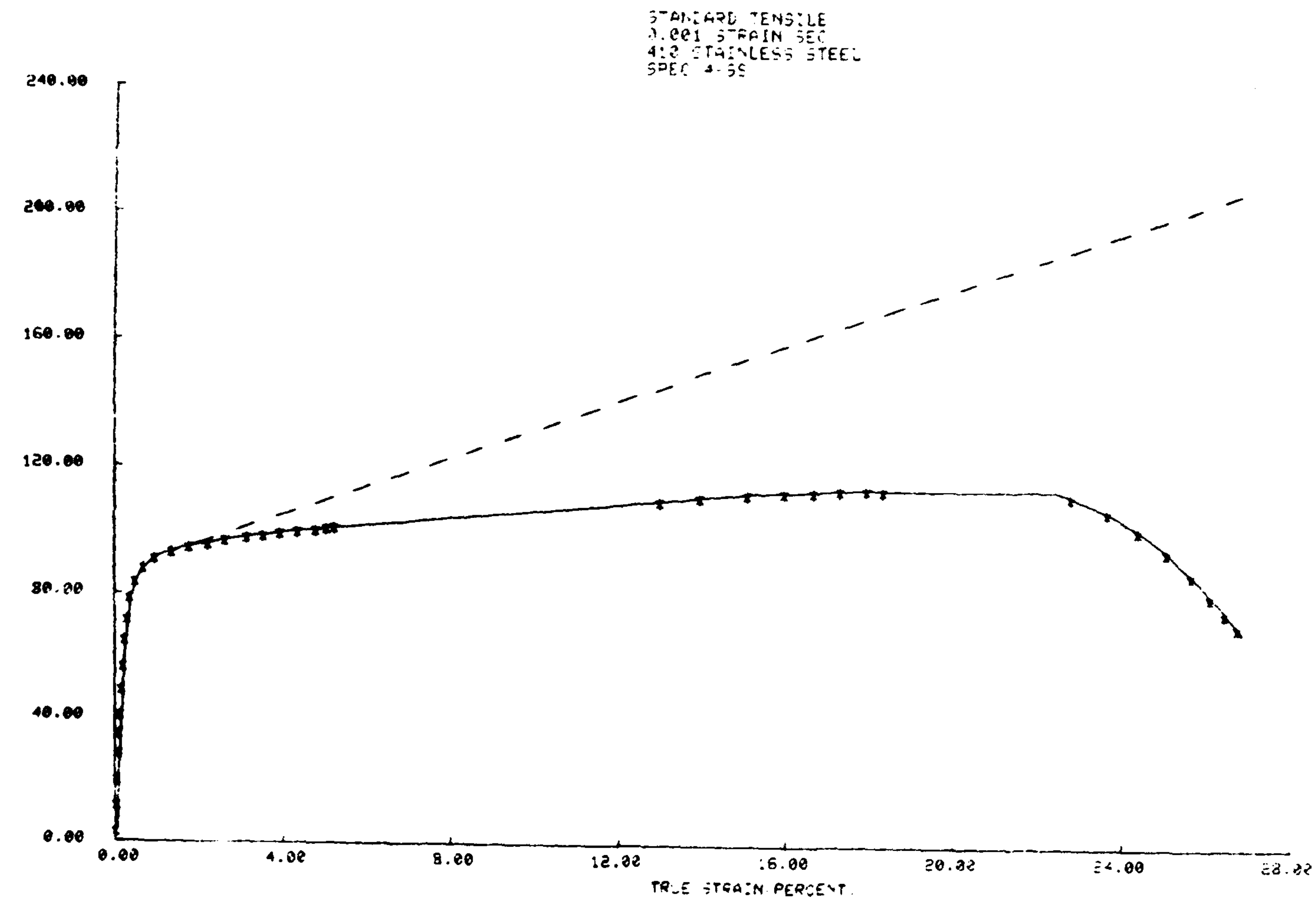
80.00
120.00
160.00
200.00
240.00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0.001 STRAIN SEC
410 STAINLESS STEEL
SPEC 4-59
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200.00
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120.00
80.00
40.00
0.00
TRUE STRESS (KSI)
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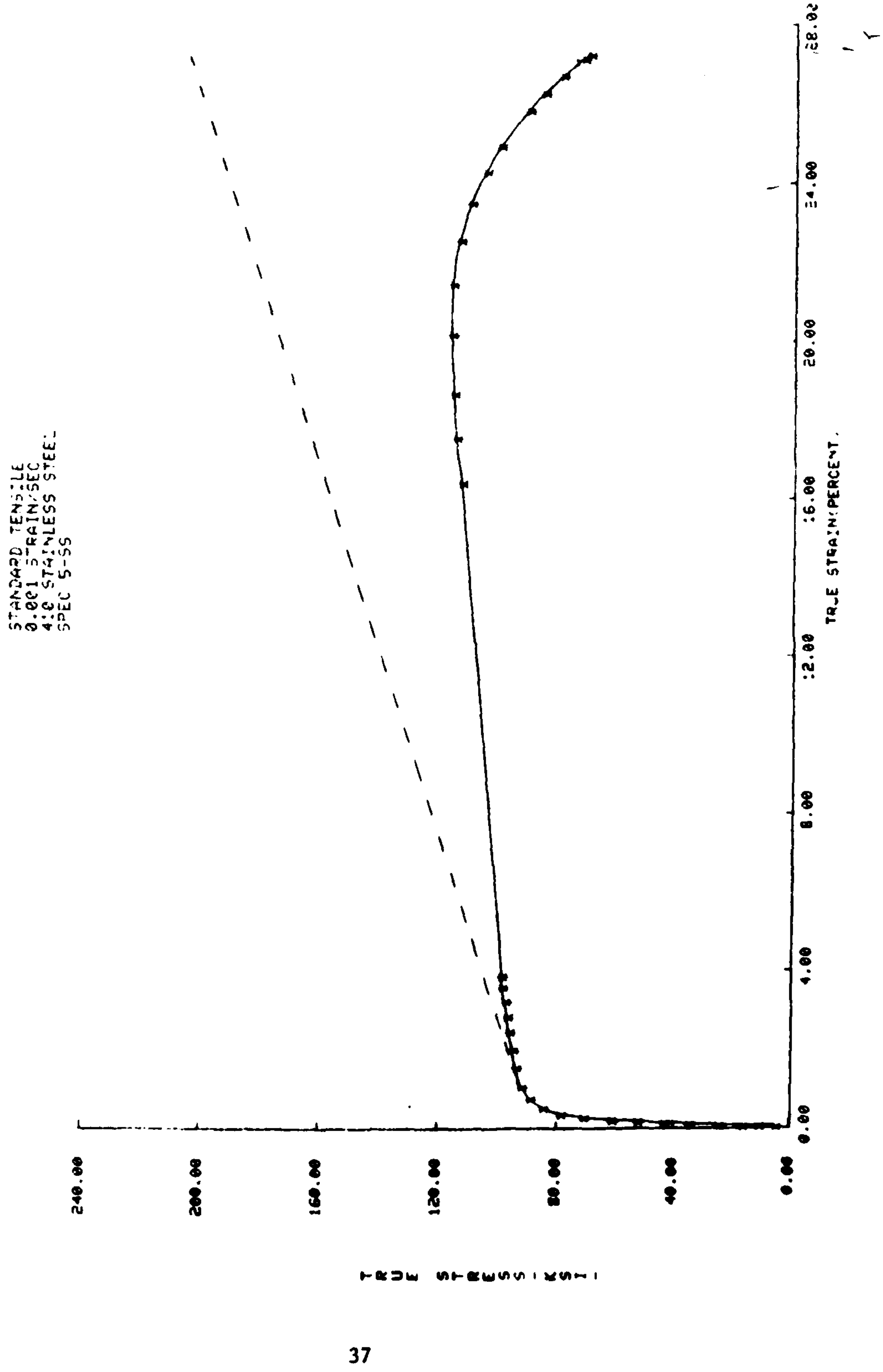
12.00
16.00
20.00
24.00
28.00
TRUE STRAIN PERCENT



STANDARD TENSILE
0.001 STRAIN/SEC
410 STAINLESS STEEL
SPEC 5-SS
TRUE STRAIN(PERCENT)
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12.00
16.00
20.00
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28.00
TRUE STRESS(KSI)
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200.00
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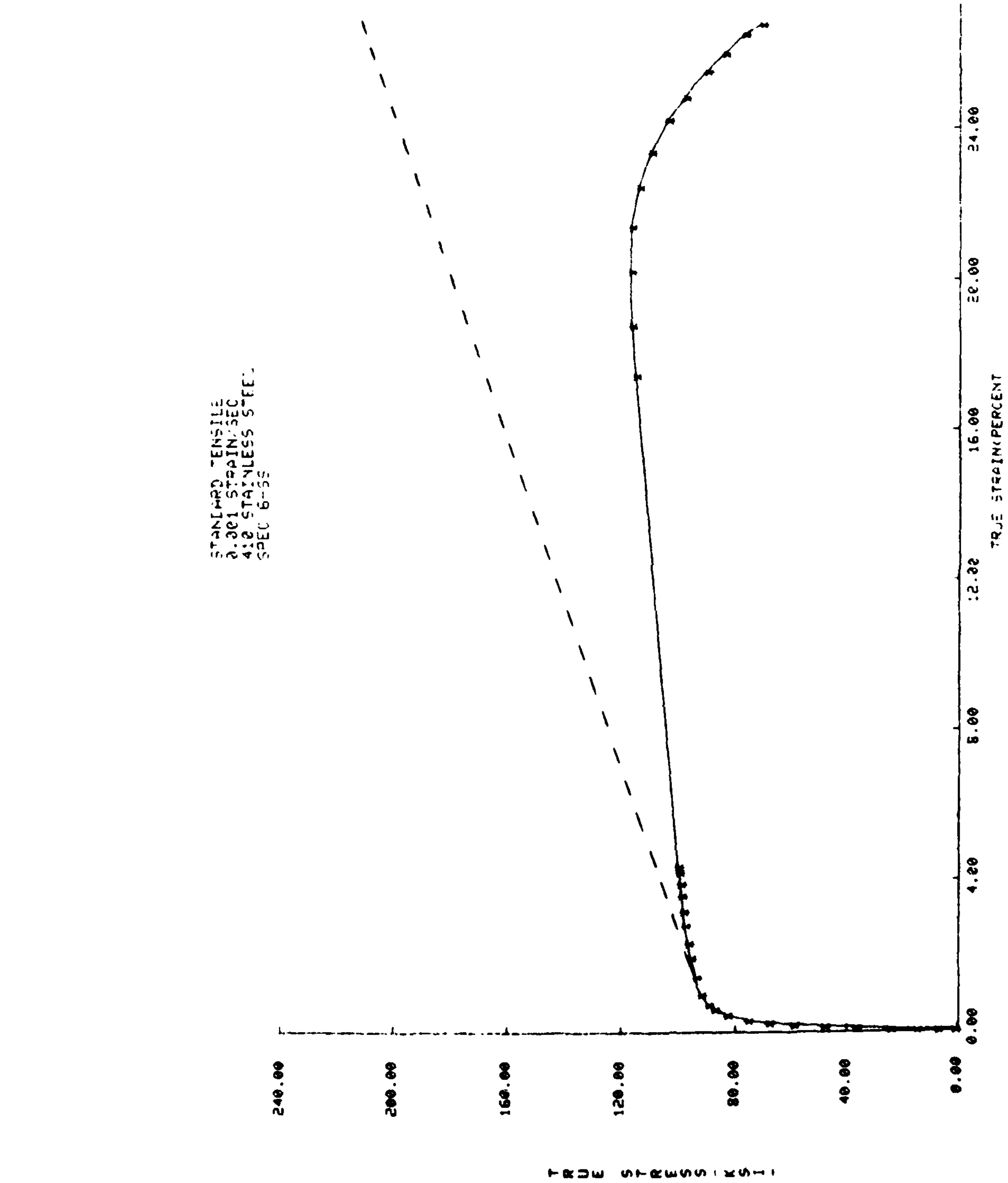
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410 STAINLESS STEEL
SPEC 6-5S
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160.00
200.00
240.00
TRUE STRAIN(PERCENT)
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8.00
12.00
16.00
20.00
24.00

STANDARD TENSILE
0.100 STRAIN/SEC
8AL-1MO-1V TITANIUM
SPEC 4-TI

1	.03935636	3.257
2	.09800508	10.586
3	.15638171	19.547
4	.21490247	27.294
5	.25340253	35.854
6	.33130742	46.468
7	.38925160	57.491
8	.42774387	65.659
9	.46604360	75.053
10	.54401987	84.065
11	.60184096	95.112
12	.64060636	100.849
13	.65939212	107.800
14	.71779652	114.372
15	.73650880	121.735
16	.75545377	127.467
17	.81327086	137.725
18	.87152658	144.720
19	.89032801	151.276
20	.94877471	156.643
21	1.12597012	158.445
22	1.36217390	157.985
23	1.59776250	157.962
24	1.93054144	158.097
25	2.24268198	158.611
26	2.57309316	160.402
27	3.13423510	163.428
28	3.71172878	164.412
29	4.26676334	165.786
30	4.79974945	167.132
31	5.34901999	166.809
32	5.97021255	167.891
33	6.43831310	168.280
34	7.07130284	169.827
35	7.73724689	171.008
36	8.38057783	171.278
37	8.98344017	171.030
38	9.47397752	171.017
39	10.19636066	170.518
40	10.73485088	169.227
41	11.28830543	167.491
42	11.89194646	164.450
43	12.36882362	161.153
44	12.82591671	157.787
45	13.24598632	154.789

STANDARD TENSILE
0.100 STRAIN/SEC
8AL-1MO-1V TITANIUM
SPEC 5-TI

1	.05654797	3.271
2	.10870553	11.008
3	.12265188	17.106
4	.19267119	26.891
5	.24475782	34.641
6	.29444439	44.833
7	.34450159	54.625
8	.37627846	62.781
9	.42550477	73.394
10	.47628597	82.388
11	.52625225	92.199
12	.55599913	102.404
13	.58810322	110.171
14	.62098541	117.127
15	.65267456	125.307
16	.70491609	132.698
17	.73736615	140.070
18	.77177377	145.410
19	.82670694	149.961
20	.82355972	153.219
21	.94080533	154.591
22	1.07879180	154.766
23	1.21697999	154.611
24	1.35497748	154.473
25	1.57044257	155.306
26	1.98085383	156.529
27	2.31140082	158.013
28	2.67925197	159.996
29	3.10483700	160.861
30	3.47093574	161.609
31	3.91194067	162.936
32	4.44666631	164.045
33	4.96035564	164.269
34	5.52645895	166.310
35	6.22230569	166.499
36	6.65211026	166.982
37	7.33945767	168.020
38	7.91215402	168.381
39	8.37140514	168.936
40	8.73736618	169.290
41	9.17541029	168.917
42	9.70158121	169.176
43	10.17069419	169.756
44	10.56669295	169.280
45	11.03284015	168.501
46	11.56673857	169.221
47	12.15177187	168.690
48	12.69868228	167.607
49	13.22621626	165.083
50	13.62908264	162.723
51	14.08292549	159.521
52	14.44755739	157.500
53	15.24399454	149.787
54	15.55330532	147.591
55	15.81033547	145.748
56	15.96525145	143.217

STANDARD TENSILE
0.100 STRAIN/SEC
8AL-1MO-1V TITANIUM
SPEC 6-TI

1	.03471530	3.667
2	.06652873	9.359
3	.13416839	17.916
4	.17952807	28.084
5	.22429013	38.663
6	.27306970	46.410
7	.32124898	54.567
8	.36710015	64.350
9	.47082861	75.415
10	.51661125	85.211
11	.56697375	91.767
12	.59804342	97.897
13	.62852871	104.436
14	.69349202	114.679
15	.74032105	123.685
16	.80693294	132.722
17	.87464714	140.954
18	.88640938	146.669
19	.91967226	151.195
20	.93372116	155.287
21	1.12844386	157.609
22	1.22766277	157.348
23	1.32621259	157.500
24	1.46515929	156.985
25	1.64319673	156.553
26	1.93733236	157.193
27	2.17145361	158.115
28	2.42451498	159.084
29	2.67637448	160.467
30	3.14007390	162.747
31	3.44913410	163.444
32	3.98770165	164.666
33	4.42849011	165.253
34	4.77222466	165.620
35	5.22852417	166.249
36	5.68275105	166.876
37	6.20999722	167.677
38	6.62237795	167.785
39	6.95872451	168.574
40	7.42317698	169.673
41	7.94188394	170.038
42	8.40233466	170.702
43	8.76981055	170.706
44	9.22700084	170.925
45	9.60907468	171.406
46	9.95512767	170.467
47	10.40694295	170.669
48	10.80246422	171.183
49	11.19746146	170.797
50	11.66147829	171.028
51	12.05515430	168.814
52	12.53385115	168.157
53	13.10192704	164.035
54	13.36780151	161.452
55	13.80852118	157.880
56	14.24730702	154.271
57	14.59795432	150.426
58	14.98125574	147.095
59	15.31320832	142.215

STANDARD TENSILE
0.100 STRAIN/SEC
410 STAINLESS STEEL
SPEC 9-SS

1	.00035853	.203
2	.00896298	5.063
3	.02366054	13.368
4	.03584711	20.256
5	.08648913	26.339
6	.09795168	32.825
7	.15035226	39.928
8	.12266335	46.814
9	.13340565	52.898
10	.18185101	57.777
11	.14915893	61.821
12	.19723884	66.500
13	.24708391	72.197
14	.29690415	77.897
15	.38147019	80.774
16	.38789905	84.431
17	.47274506	87.516
18	.91840081	93.369
19	1.27692285	95.530
20	1.90832474	97.753
21	2.76864879	100.011
22	3.58243795	101.836
23	4.46534833	103.329
24	5.49178148	104.984
25	6.54450926	106.257
26	7.28915843	106.794
27	8.21265215	107.736
28	9.27332846	108.827
29	10.39420405	109.543
30	11.46674946	109.983
31	12.42284052	110.755
32	13.12544181	111.495
33	13.99556107	111.487
34	14.99570225	111.608
35	15.67929211	111.385
36	16.52665221	110.611
37	17.26618215	109.703
38	17.86652894	108.392
39	18.66132649	106.526
40	19.44867614	103.633
41	20.13318117	101.580
42	20.81303257	99.488
43	21.32688160	96.964
44	21.99725420	93.540
45	22.72621590	89.606
46	23.48061967	84.563
47	24.04264046	81.188
48	24.50812256	77.659
49	24.97088934	73.575
50	25.21572951	70.356
51	25.49174514	67.922
52	25.76644683	64.950

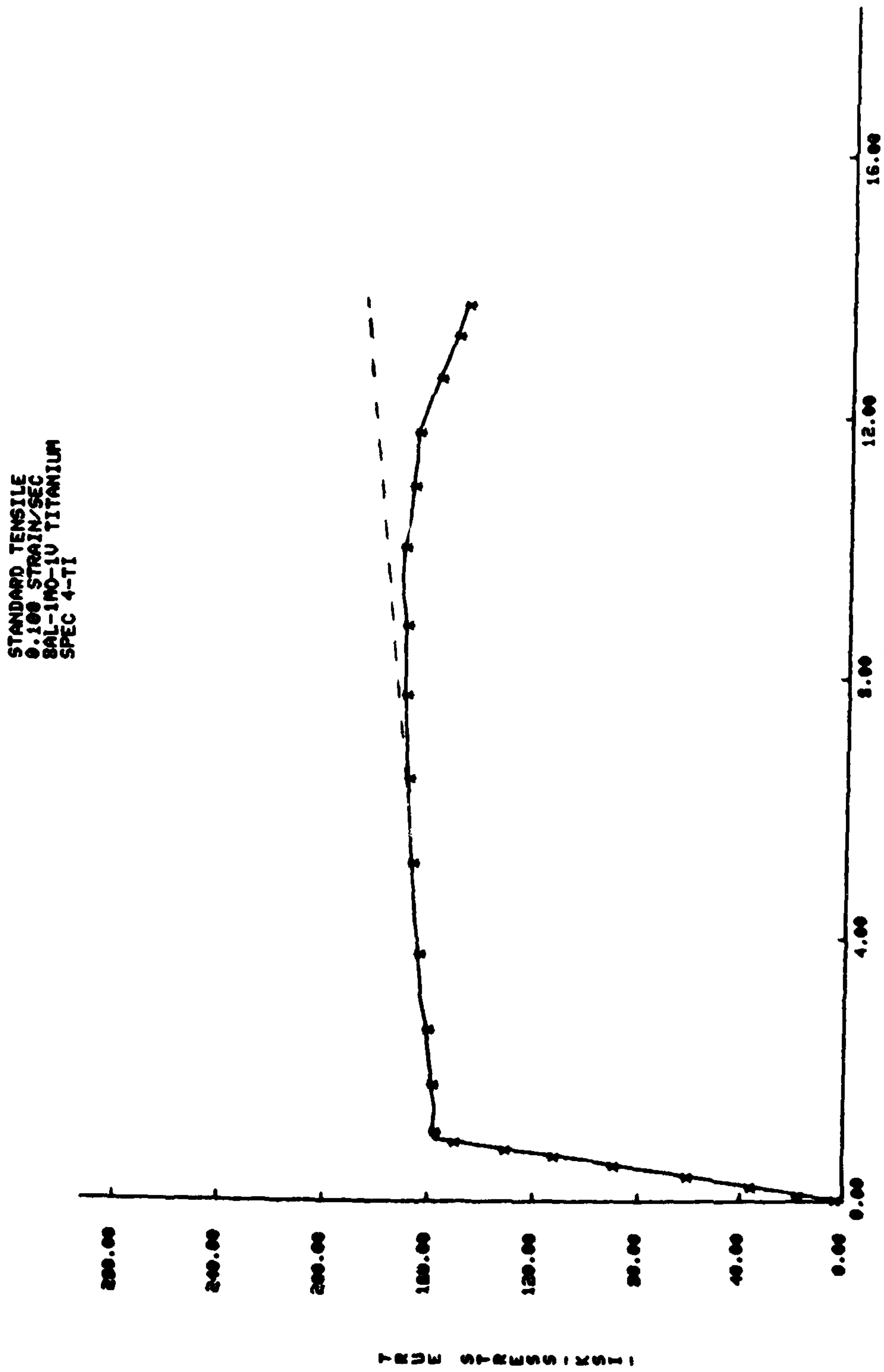
STANDARD TENSILE

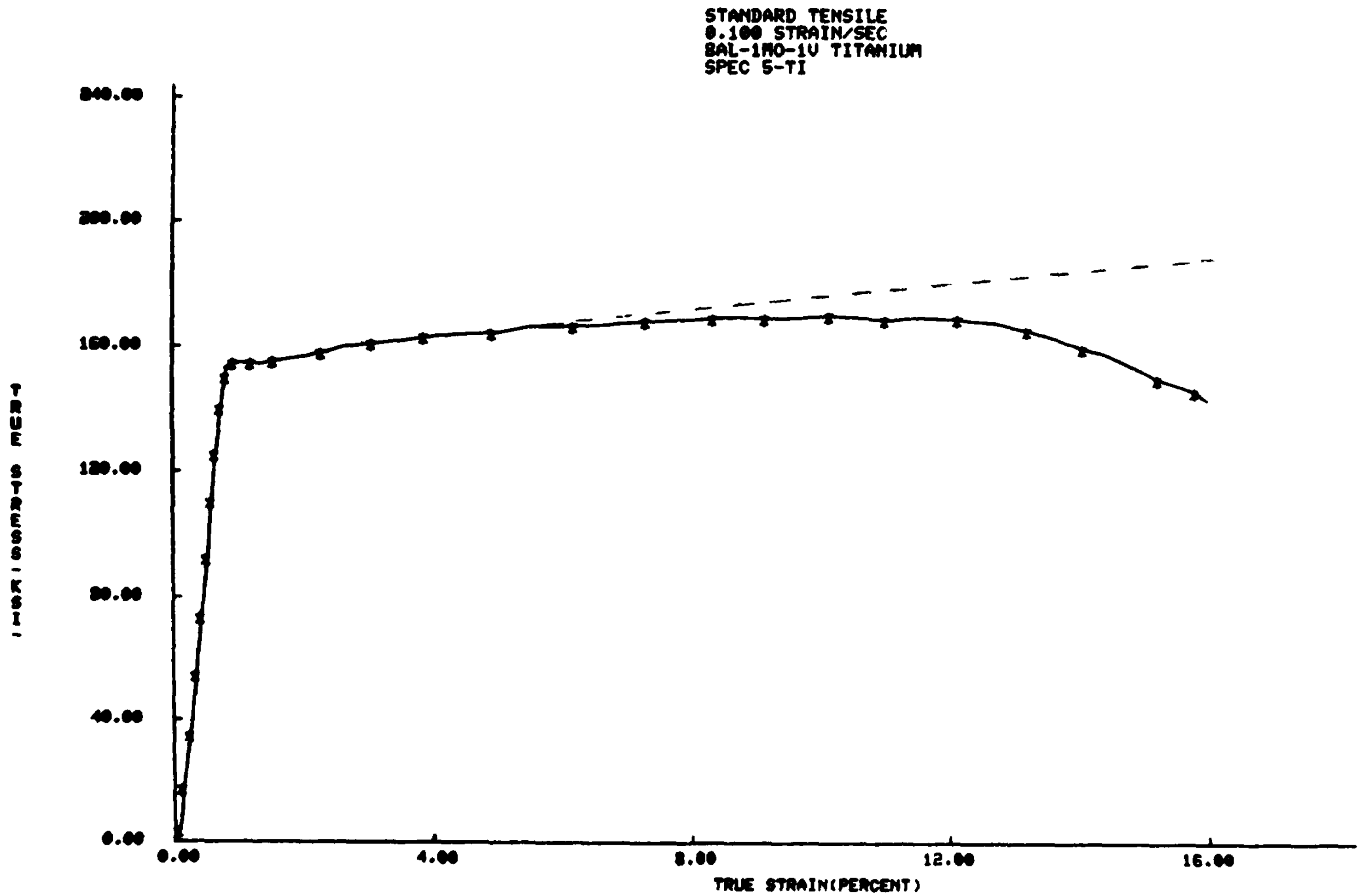
0.100 STRAIN/SEC
410 STAINLESS STEEL
SPEC 10-SS

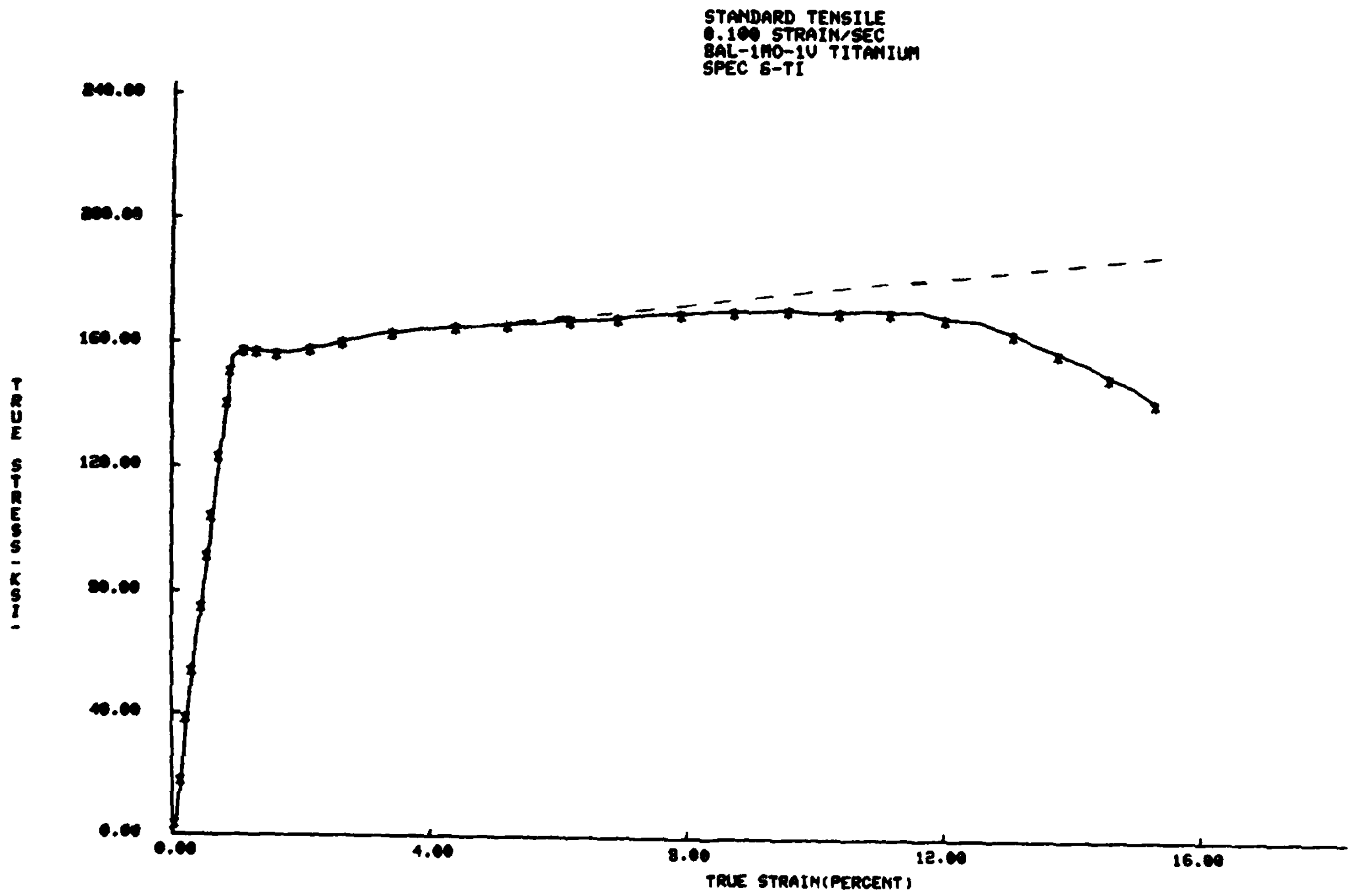
1	0.00000000	0.000
2	.01210789	3.239
3	.04877515	8.310
4	.06218912	15.403
5	.10791047	24.531
6	.11829335	32.438
7	.17305414	39.144
8	.18116430	47.661
9	.19682618	54.156
10	.17567809	59.823
11	.15754759	64.680
12	.22436764	68.160
13	.24757130	72.633
14	.27001492	77.311
15	.37350818	81.631
16	.47840062	85.550
17	.58468773	89.083
18	.81268690	91.957
19	1.12061854	94.519
20	1.54853608	96.403
21	2.20984863	98.348
22	2.90558705	100.354
23	3.63792577	101.586
24	4.25027029	102.695
25	5.08670736	104.071
26	5.95452543	105.286
27	6.70298396	106.375
28	7.59534481	107.210
29	8.58904225	108.393
30	9.39286159	108.917
31	10.19027116	109.435
32	11.01644387	110.216
33	11.80240655	110.271
34	12.82692057	111.073
35	14.05325846	110.738
36	15.09070747	111.087
37	16.15403901	110.515
38	17.31074385	108.593
39	18.15262109	107.204
40	18.85661755	105.132
41	19.82161320	101.853
42	20.58144965	98.768
43	21.17300813	95.944
44	21.79379290	92.864
45	22.44384566	89.268
46	23.12257405	85.141
47	23.63693888	81.819
48	24.11791677	78.173
49	24.50115880	75.177
50	24.81950740	72.618
51	25.13743427	69.782
52	25.32935102	67.343
53	25.48880529	65.390

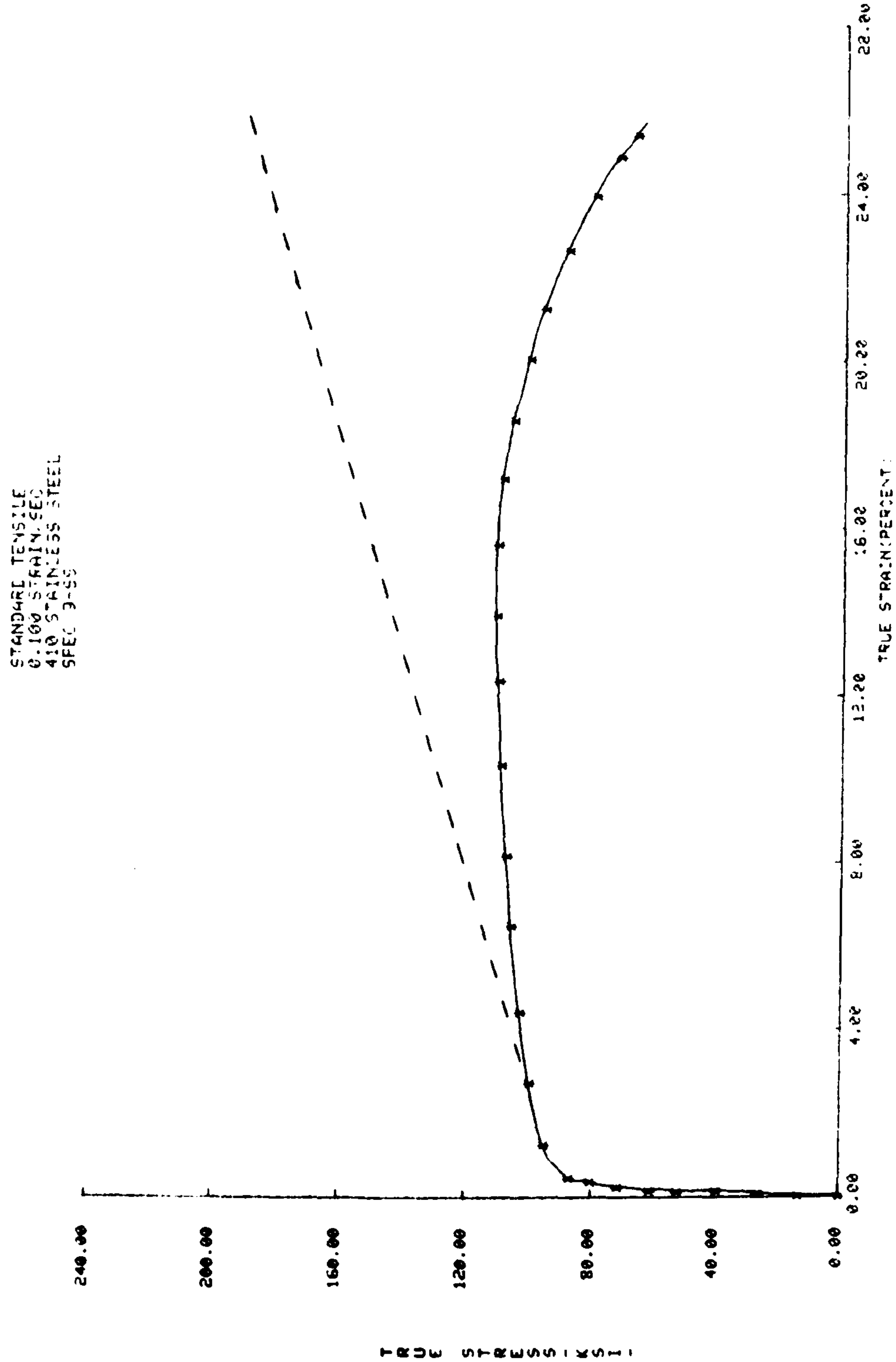
STANDARD TENSILE
0.100 STRAIN/SEC
410 STAINLESS STEEL
SPEC 11-SS

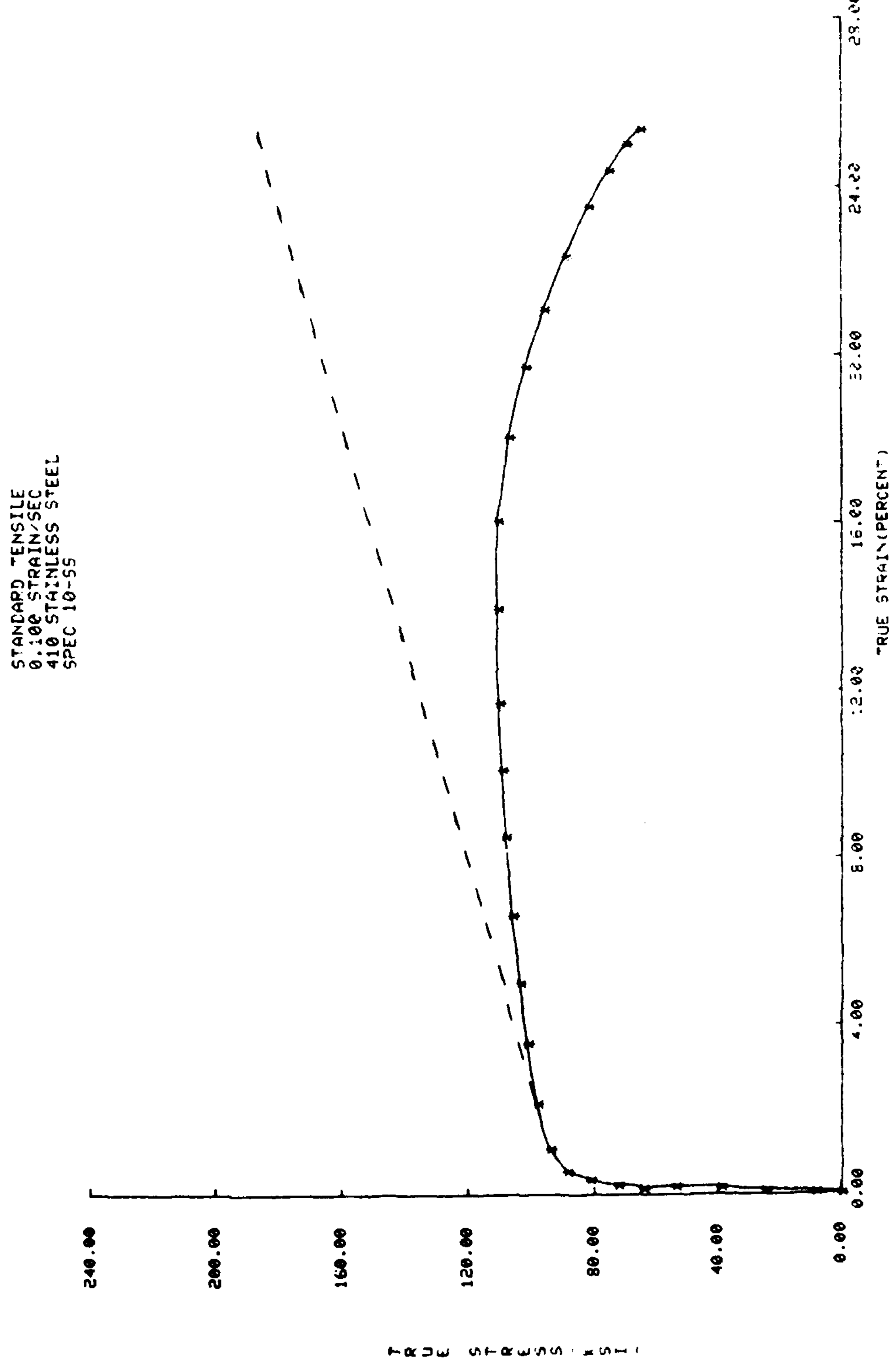
1	0.00000000	.608
2	.03991219	7.090
3	.03991219	12.155
4	.07980846	18.237
5	.07980846	24.113
6	.07980846	30.800
7	.11968882	37.293
8	.11968882	42.968
9	.11968882	48.440
10	.15955328	53.722
11	.15955328	58.588
12	.15955328	61.831
13	.19940186	66.510
14	.23923456	71.596
15	.27905141	74.859
16	.27905141	77.699
17	.31885240	80.761
18	.31885240	83.399
19	.31885240	86.037
20	.35863756	88.290
21	.47789816	90.383
22	.71599351	92.814
23	1.11156365	95.634
24	1.78046246	98.539
25	2.40595317	99.779
26	3.22101687	101.639
27	4.33576991	103.622
28	5.24901826	105.212
29	6.45385211	106.487
30	8.08714752	108.021
31	8.71111724	109.139
32	9.51287081	109.350
33	10.30824738	110.000
34	11.24015376	110.351
35	11.80934776	110.526
36	12.69227774	110.589
37	13.91542771	110.091
38	14.88328870	108.582
39	15.94403432	107.607
40	16.62246298	106.431
41	17.56459646	103.343
42	18.06568319	101.925
43	18.53110956	99.239
44	19.22521250	96.011
45	20.14325173	92.694
46	20.79387212	88.323
47	21.56906980	84.247
48	21.98647288	80.822
49	22.56155433	76.984
50	23.00656460	73.003
51	23.32322038	70.427
52	23.54428534	68.282
53	23.73338038	66.105


STANDARD TENSILE
0.100 STRAIN/SEC
8AL-1MO-1V TITANIUM
SPEC 4-TI
TRUE STRESS(KSI)
0.00
40.00
80.00
120.00
160.00
200.00
240.00
280.00
TRUE STRAIN(PERCENT)
4.00
8.00
12.00
16.00

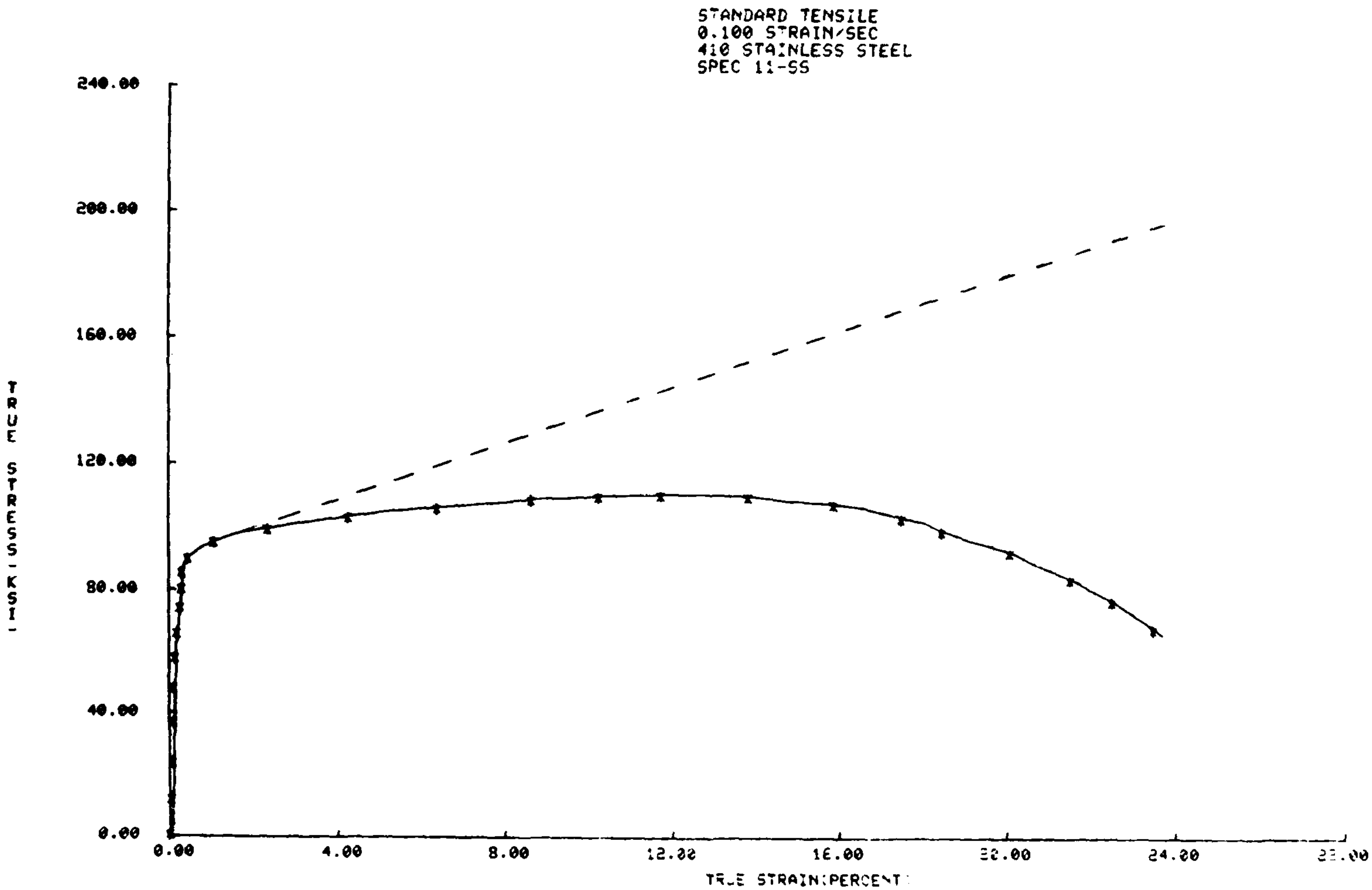

STANDARD TENSILE
0.100 STRAIN/SEC
8AL-1MO-1V TITANIUM
SPEC 5-TI
TRUE STRESS(KSI)
240.00
200.00
160.00
120.00
80.00
40.00
0.00
0.00
4.00
8.00
12.00
16.00
TRUE STRAIN(PERCENT)


STANDARD TENSILE
0.100 STRAIN/SEC
8AL-1MO-1V TITANIUM
SPEC 6-TI
240.00
200.00
160.00
120.00
80.00
40.00
0.00
TRUE STRESS(KSI)
0.00
4.00
8.00
12.00
16.00
TRUE STRAIN(PERCENT)


STANDARD TENSILE
0.100 STRAIN/SEC
410 STAINLESS STEEL
SPEC 3-55
TRUE STRESS(KSI)
TRUE STRAIN(PERCENT)
0.00
40.00
80.00
120.00
160.00
200.00
240.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00



STANDARD TENSILE
0.100 STRAIN/SEC
410 STAINLESS STEEL
SPEC 10-55
TRUE STRAIN(PERCENT)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
0.00
40.00
80.00
120.00
160.00
200.00
240.00


STANDARD TENSILE
0.100 STRAIN/SEC
410 STAINLESS STEEL
SPEC 11-SS
TRUE STRESS-KSI-
240.00
200.00
160.00
120.00
80.00
40.00
0.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
TRUE STRAIN(PERCENT)

STANDARD TENSILE
1 STRAIN/SEC
410 STAINLESS STEEL
12-SS

1	0.00000000	0.000
2	.03375393	1.833
3	.02970882	3.053
4	.01959532	6.102
5	.05334264	7.937
6	.04120919	11.596
7	.07292752	14.042
8	.06551426	16.278
9	.05742644	18.717
10	.08846582	21.368
11	.07768440	24.620
12	.07364106	25.840
13	.06555391	28.278
14	.10063317	29.711
15	.09456950	31.541
16	.08783165	33.573
17	.12155595	35.414
18	.11414630	37.650
19	.10538873	40.292
20	.13843365	42.337
21	.12900468	45.183
22	.12092200	47.622
23	.14857474	51.295
24	.17891266	54.156
25	.16746771	57.611
26	.15938814	60.050
27	.19106900	62.507
28	.21937528	65.980
29	.20658896	69.842
30	.19851255	72.281
31	.23018102	74.740
32	.21806902	78.398
33	.24838586	81.266
34	.23829446	84.314
35	.23291196	85.940
36	.27062292	86.573
37	.38568597	87.864
38	.45963599	89.540
39	.61273456	91.293
40	.76559909	93.081
41	.99779722	94.752
42	1.30811156	96.513
43	1.73563019	98.203
44	2.12366414	99.449
45	2.54903252	100.744
46	3.08982778	101.758
47	3.62771417	102.777
48	4.23781135	104.310
49	5.03439941	105.960
50	5.63918727	106.345
51	6.24033942	106.829
52	7.17148336	107.921
53	7.76414532	108.183
54	8.27815152	109.013
55	8.97236890	105.844
56	9.29953415	110.238
57	9.84244214	110.895
58	10.38302644	111.328
59	10.92070414	111.760
60	11.45610771	111.963
61	12.02458109	111.977
62	12.58865185	112.442
63	13.08087454	112.359
64	13.64021175	112.354
65	14.29947326	112.705
66	14.85379838	111.983
67	15.40448956	111.483
68	16.12409898	110.228
69	16.73754559	108.822
70	17.38186599	106.948
71	17.95382701	105.690
72	18.42432343	103.808
73	18.76063940	101.752
74	19.32868171	98.712
75	19.82765279	95.807
76	20.22273092	94.498
77	20.58658465	91.899
78	20.91571847	89.745
79	21.40739690	86.482
80	21.73438726	84.036
81	22.25395437	80.742
82	22.64495784	76.786
83	23.06446173	73.589
84	23.35616003	70.257
85	23.54944340	68.365
86	23.80462585	66.774

STANDARD TENSILE
1 STRAIN/SEC
410 STAINLESS STEEL
13-SS

1	.00166925	.407
2	.01085061	2.643
3	.01983012	4.884
4	.00898166	7.527
5	.00520655	10.982
6	.01545909	15.664
7	.04529750	18.112
8	.03111444	21.567
9	.05510926	25.438
10	.07159243	31.140
11	.08557121	37.452
12	.10621810	42.140
13	.09204367	45.594
14	.11185555	50.486
15	.13583100	54.364
16	.15563420	59.258
17	.13563255	64.134
18	.15793573	68.420
19	.18190014	72.301

20	.16190374	77.177
21	.19586350	78.621
22	.18836637	80.450
23	.17836932	82.887
24	.20649340	85.755
25	.27270646	89.055
26	.45549639	93.046
27	.64707478	94.834
28	1.03326429	97.498
29	1.37948193	99.931
30	1.88356488	101.939
31	2.81236251	104.455
32	3.73341684	106.791
33	4.72373480	108.820
34	5.44437738	109.478
35	6.53241432	111.024
36	7.38916581	111.648
37	8.27303800	112.970
38	8.78625555	113.395
39	9.58853940	113.741
40	10.20386748	114.074
41	11.06480767	114.947
42	12.09664200	115.592
43	12.94370767	115.768
44	14.20027862	116.239
45	15.20113769	116.607
46	16.12637927	116.157
47	17.07674931	115.724
48	18.25580036	113.866
49	19.25959820	110.743
50	20.18965413	106.959
51	20.98059762	103.431
52	21.83011638	99.657

STANDARD TENSILE
1 STRAIN/SEC
410 STAINLESS STEEL
14-SS

1	.07898837	.211
2	.07398391	1.635
3	.06468926	4.279
4	.08951279	8.555
5	.11147150	13.647
6	.12913822	19.960
7	.12913822	19.960
8	.11484629	24.027
9	.14037183	28.105
10	.16374799	32.793
11	.18569042	37.890
12	.20976996	42.378
13	.22884700	48.291
14	.25220249	52.984
15	.27269848	58.493
16	.29390365	63.800
17	.31439110	69.311
18	.33772662	74.010
19	.35677927	79.931
20	.38010490	84.633
21	.40627541	88.522

22	.39772422	90.963
23	.42745227	93.836
24	.50752756	93.684
25	.62076572	95.407
26	.77486389	96.796
27	1.04573568	98.724
28	1.55238006	100.716
29	2.25016111	103.355
30	2.71474703	104.506
31	3.44854754	105.558
32	4.48105992	107.392
33	4.48037580	107.604
34	5.12429817	109.005
35	6.10425811	110.179
36	6.70190261	111.118
37	7.48246464	111.853
38	8.29434075	112.411
39	8.91620445	113.180
40	9.53422489	113.950
41	10.32903312	114.723
42	10.94097506	114.591
43	11.58152174	115.628
44	12.11462387	115.621
45	12.43198903	116.026
46	12.96058844	116.010
47	13.76472168	116.345
48	14.18260728	116.181
49	15.11420691	116.675
50	15.87031480	115.752
51	16.69006751	114.172
52	17.60530250	111.952
53	18.21123596	110.277
54	18.57906909	109.511
55	19.31541953	105.988
56	19.87960730	103.694
57	20.27859557	100.932
58	20.99968239	98.508
59	21.45859233	95.756
60	21.85249242	92.402
61	22.24312869	89.778
62	22.72814785	86.973
63	23.05265404	83.981
64	23.53546838	80.350
65	23.85962393	76.279
66	24.21178440	73.240
67	24.50087974	69.866
68	24.63177085	67.121

STANDARD TENSILE
1 STRAIN/SEC
410 STAINLESS STEEL
15-SS

1	0.00000000	0.000
2	.00286832	1.624
3	.00681240	3.858
4	.01398386	7.918
5	.02198775	10.155
6	.01661076	13.201
7	.05185467	15.846

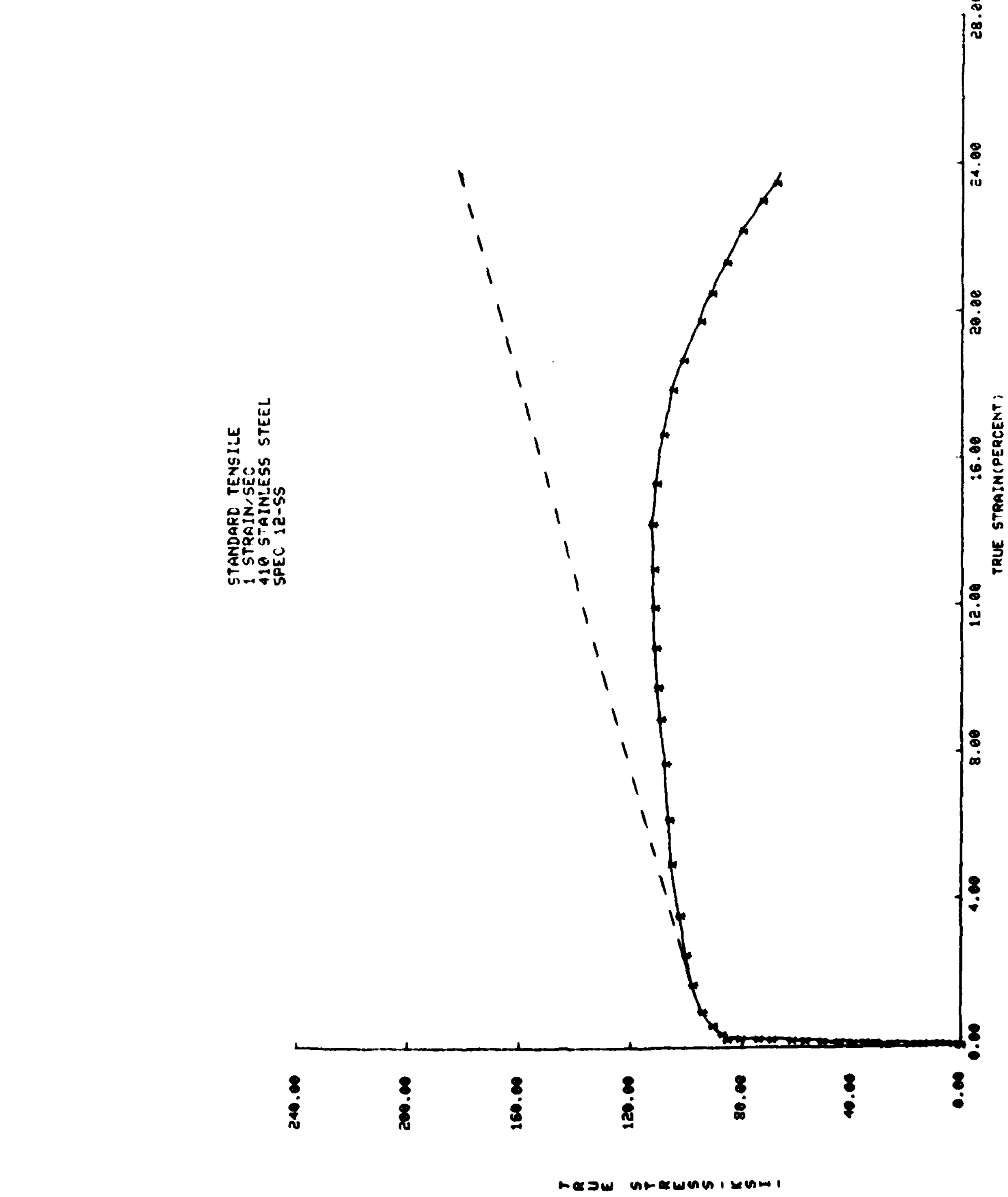
8	.08314563	20.726
9	.07490583	25.398
10	.10511511	30.890
11	.13531527	36.384
12	.16658013	41.270
13	.15798924	46.146
14	.19032058	50.425
15	.22299920	54.503
16	.21441315	59.380
17	.24636861	63.866
18	.27724123	68.964
19	.26973255	73.232
20	.30202779	77.519
21	.33395526	82.012
22	.33002444	84.248
23	.44823874	84.923
24	.48190365	88.404
25	.63711518	90.561
26	.79279759	92.343
27	.98777041	94.169
28	1.22144962	96.246
29	1.57359482	97.837
30	2.08100610	99.600
31	2.46944344	101.045
32	3.16658769	102.622
33	3.97440149	104.126
34	4.62340428	105.473
35	5.45704594	107.254
36	5.98514684	107.634
37	6.69629764	108.872
38	7.18176823	108.557
39	7.84759224	109.756
40	8.43599318	110.656
41	9.24020904	111.371
42	10.25440222	112.338
43	11.08024109	112.864
44	11.65093579	113.087
45	12.32431366	113.432
46	12.74751305	113.478
47	13.41357156	113.812
48	13.97082905	114.249
49	14.69807072	114.423
50	15.31767822	114.228
51	16.13718251	114.505
52	16.74826724	114.048
53	17.62463821	113.175
54	18.29562617	110.818
55	18.82877786	109.245
56	19.59025592	106.927
57	20.14949870	105.087
58	20.67375779	102.685
59	21.32466073	100.141
60	24.87299021	75.180
61	25.15636457	72.027
62	25.46905083	69.663
63	25.62613802	67.428
64	25.69012403	65.381

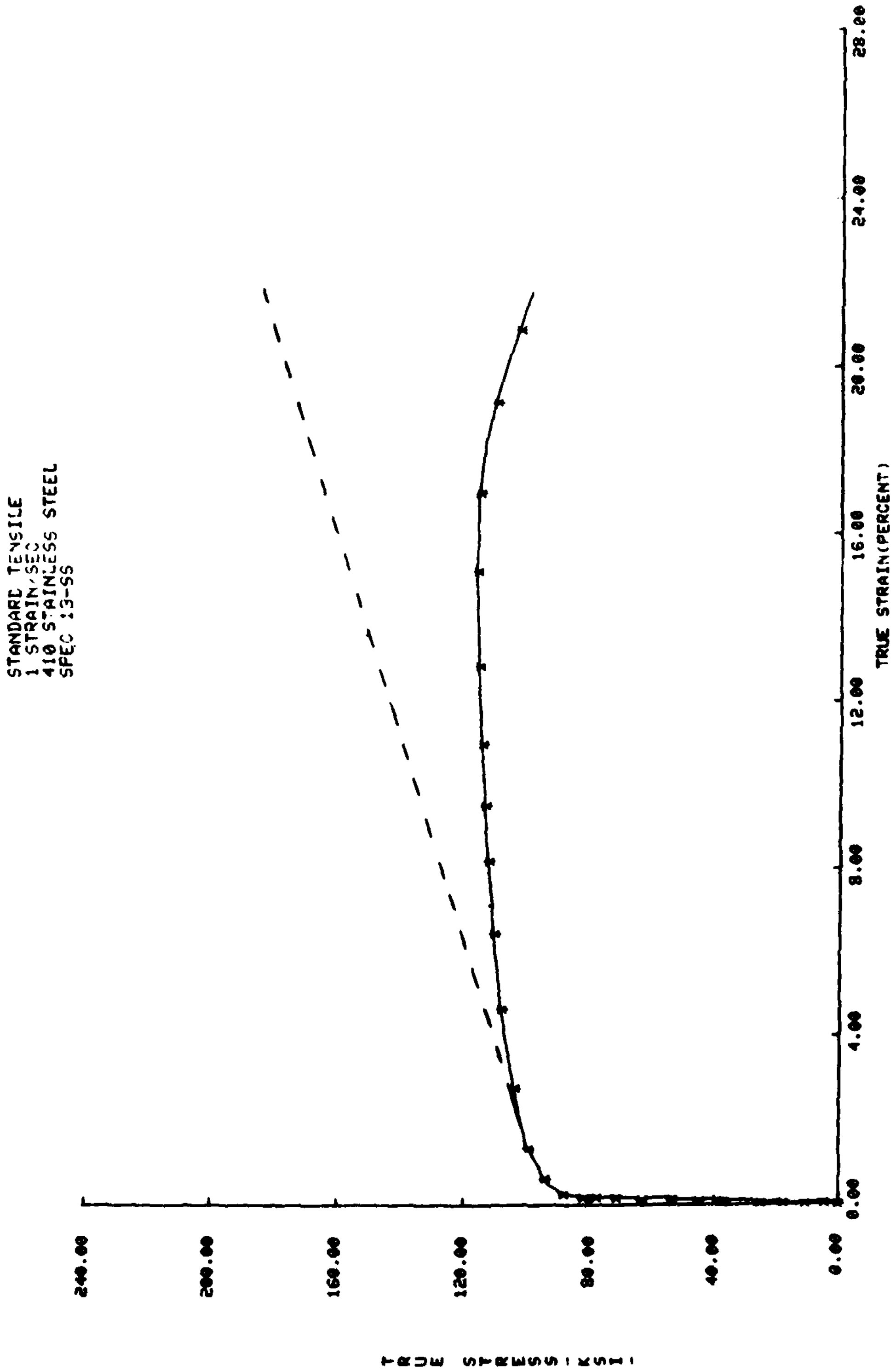
STANDARD TENSILE

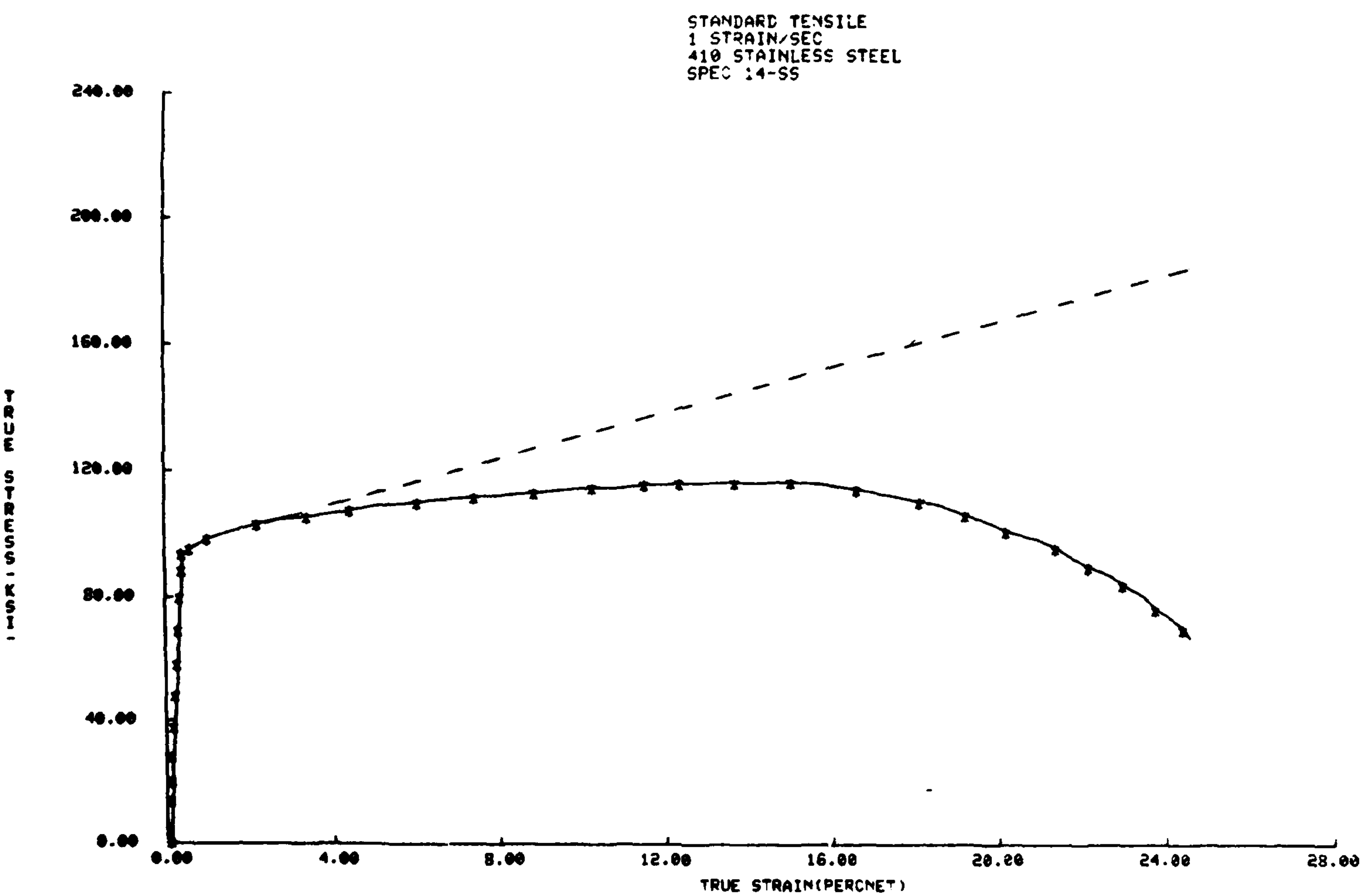
1 STRAIN/SEC
8AL-1MO-1V-TITANIUM
7-TI

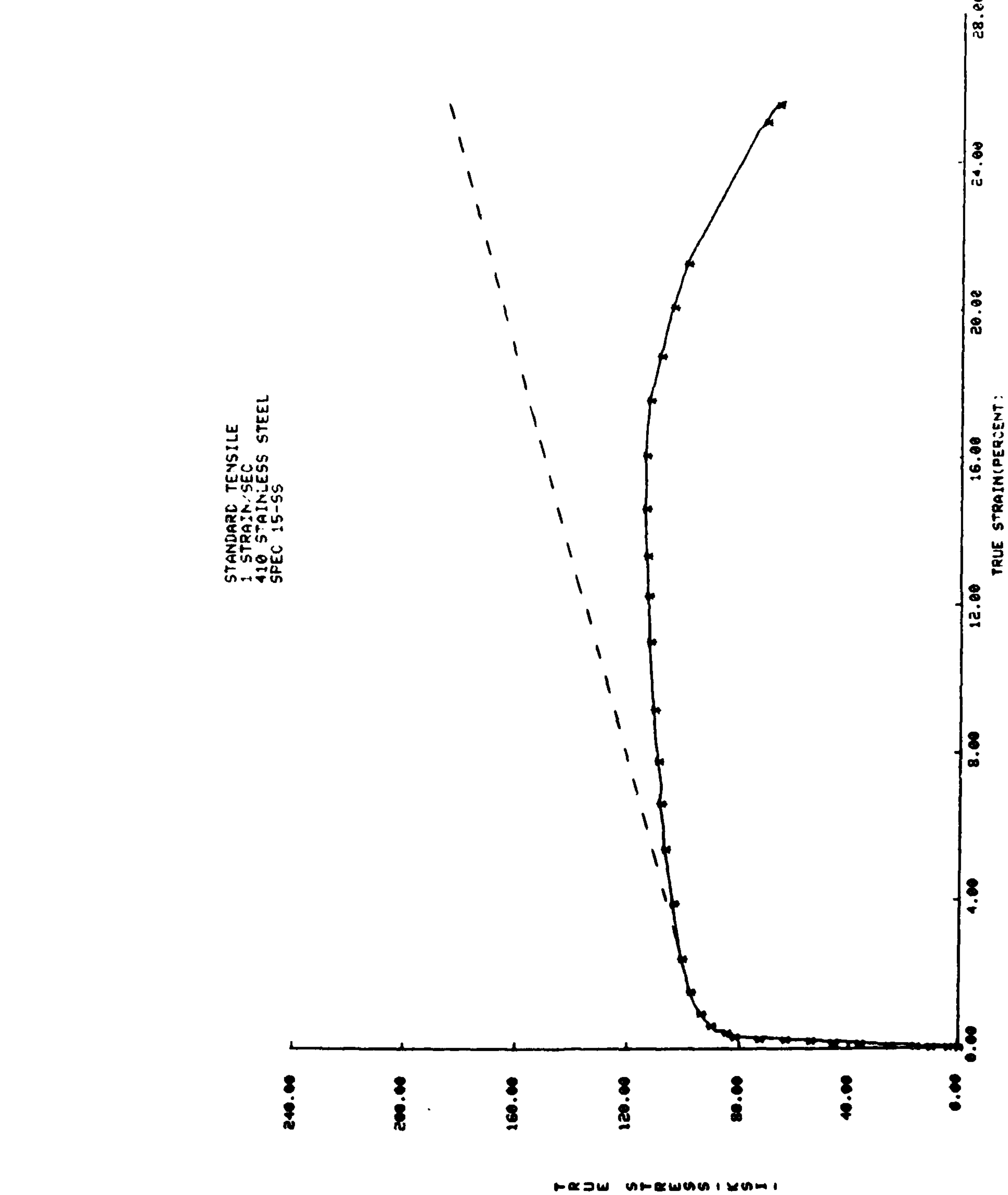
1	.01983832	.408
2	.01904327	3.655
3	.05761565	8.938
4	.07625065	14.219
5	.11460240	20.318
6	.15244320	28.450
7	.22907361	40.662
8	.26667286	49.617
9	.32363972	60.616
10	.38037609	72.436
11	.45722789	83.055
12	.51378965	95.298
13	.59014377	107.562
14	.64702546	118.193
15	.70407222	128.015
16	.76059323	139.881
17	.81777244	148.901
18	.83616776	154.627
19	.85485537	159.131
20	.87363802	163.228
21	.89310676	164.471
22	.97173135	166.184
23	1.22820981	166.038
24	1.54285478	166.557
25	2.01287627	167.802
26	2.51959359	169.122
27	3.08177673	170.552
28	3.54473286	171.394
29	4.08205791	172.796
30	4.42592879	173.851
31	4.76871603	174.486
32	5.11023780	175.546
33	5.41310865	175.260
34	5.77145139	175.502
35	6.12851461	175.742
36	6.40962166	175.408
37	6.74559444	176.469
38	7.19174777	178.177
39	7.61753604	179.423
40	8.06028316	178.959
41	8.50071347	180.241
42	8.92115808	180.609
43	9.35800238	181.010
44	9.79294664	181.407
45	10.29816654	181.046
46	10.83636932	182.091
47	11.24721632	181.989
48	11.60313074	181.777
49	12.06361657	183.130
50	12.38123761	183.753
51	12.71541340	184.412
52	13.06623678	183.726
53	13.38104198	182.502
54	13.83438360	178.757
55	14.14712880	175.639

56	14.61450618	170.453
57	14.97650819	166.432
58	15.36439273	161.938
59	15.54292849	158.970
60	15.71407078	155.960

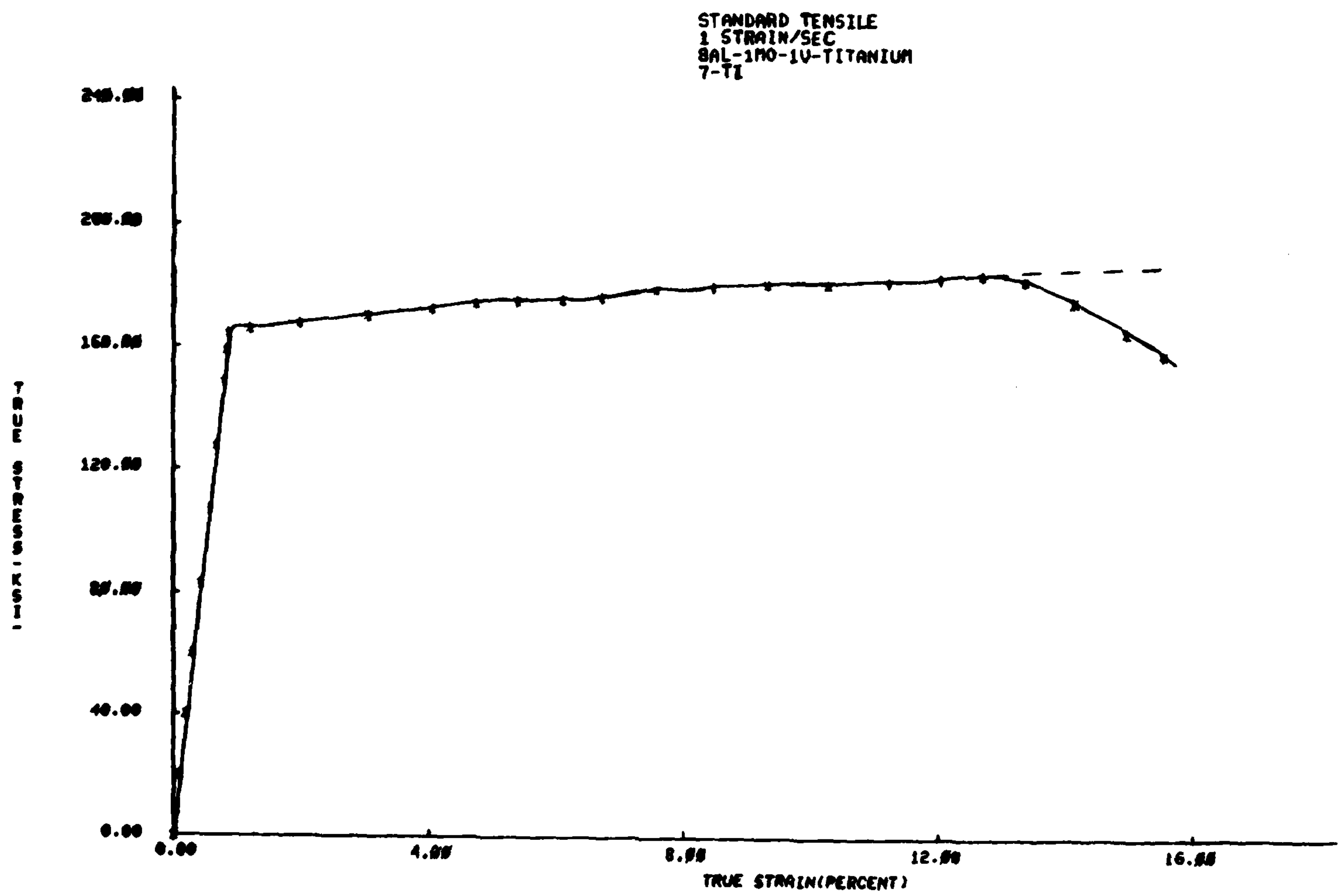

STANDARD TENSILE
1 STRAIN/SEC
410 STAINLESS STEEL
SPEC 12-SS
TRUE STRAIN(PERCENT)
TRUE STRESS(KSI)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
40.00
80.00
120.00
160.00
200.00
240.00


STANDARD TENSILE
1 STRAIN/SEC
410 STAINLESS STEEL
SPEC 13-SS
TRUE STRAIN(PERCENT)
TRUE STRESS(KSI)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
0.00
40.00
80.00
120.00
160.00
200.00
240.00


STANDARD TENSILE
1 STRAIN/SEC
410 STAINLESS STEEL
SPEC 14-SS
TRUE STRESS(KSI)
240.00
200.00
160.00
120.00
80.00
40.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
TRUE STRAIN(PERCNET)



STANDARD TENSILE
1 STRAIN/SEC
410 STAINLESS STEEL
SPEC 15-SS
TRUE STRAIN(PERCENT)
TRUE STRESS(KSI)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
40.00
80.00
120.00
160.00
200.00
240.00



STANDARD TENSILE
1 STRAIN/SEC
8AL-1MO-1V-TITANIUM
7-TI
TRUE STRESS(KSI)
TRUE STRAIN(PERCENT)
0.00
40.00
80.00
120.00
160.00
200.00
240.00
4.00
8.00
12.00
16.00

APPENDIX B

HIGH STRAIN RATE CURVES AND DIGITAL DATA

HOPKINSON BAR--TENSILE
300 STRAIN/SEC
410 STAINLESS STEEL
SPEC SS-1

1	.37970540	117.080
2	.40884080	120.080
3	.90479850	123.880
4	.90898788	125.497
5	.98878838	128.985
6	1.08480888	131.708
7	1.08088412	132.085
8	1.87877735	132.888
9	2.38481580	133.888
10	2.78078858	132.388
11	3.17718888	130.744
12	3.88888738	130.313
13	4.08488851	131.857
14	4.60048887	133.000
15	5.08877348	134.941
16	5.40185188	136.508
17	5.88388477	138.046
18	6.53888838	138.973
19	7.08888883	140.319
20	7.53773837	139.404
21	7.94371766	138.853
22	8.38518837	138.815
23	8.71478883	137.787

HOPKINSON BAR--TENSILE
530 STRAIN/SEC
410 STAINLESS STEEL
SPEC SS-2

1	.98854831	110.187
2	1.07161158	114.529
3	1.10888708	118.880
4	1.18480154	122.062
5	1.30114573	125.238
6	1.53578159	125.087
7	1.73884888	126.437
8	2.04888382	127.085
9	2.47748843	126.987
10	2.88788883	126.539
11	3.28358844	126.966
12	3.71810818	127.394
13	4.21788888	127.430
14	4.88830438	127.856
15	5.08812738	128.883
16	5.88588108	129.911
17	6.09191153	130.731
18	6.48888888	130.768
19	6.97851384	130.905
20	7.59488783	131.243
21	8.08084756	130.508
22	8.53122801	130.588
23	9.11788888	129.573
24	9.44858708	130.588
25	10.13487183	130.256
26	10.48518884	130.681
27	10.98838170	130.324
28	11.48788888	129.982
29	11.71878883	129.905
30	12.13887181	129.823
31	12.63308815	129.886
32	13.08848583	127.383

HOPKINSON BAR--TENSILE
700 STRAIN/SEC
410 STAINLESS STEEL
SPEC SS-3

1	1.08187780	117.970
2	1.33784384	123.135
3	1.41438188	128.887
4	1.53187331	131.878
5	1.78738881	133.474
6	2.18888485	133.486
7	2.74484585	132.388
8	3.38874084	131.958
9	4.13880161	131.198
10	4.88471113	132.082
11	5.38484881	132.445
12	6.07418517	133.270
13	6.88187838	132.511
14	7.53178884	132.938
15	8.18888873	133.782
16	8.85788187	134.191
17	9.44177387	134.616
18	9.84138430	134.634
19	10.88338879	134.854
20	10.81532388	134.800
21	11.84648232	133.907
22	11.98188218	135.130
23	12.38888388	134.368
24	12.94838183	134.782
25	13.40884081	135.801
26	13.88815588	136.416
27	14.20887520	137.226
28	14.54838821	139.822
29	15.08833585	140.444
30	15.88315834	139.284
31	16.18887888	138.512
32	16.73844280	136.985
33	17.14488630	135.784
34	17.54833888	133.819
35	17.88388475	132.848
36	18.05136820	131.463

HOPKINSON BAR--TENSILE
700 STRAIN/SEC
410 STAINLESS STEEL
SPEC SS-4

1	1.14488741	118.494
2	1.28114380	121.275
3	1.37788840	124.056
4	1.64074146	127.639
5	1.96115154	130.434
6	2.23884344	134.018
7	2.48448814	136.015
8	2.77467499	136.829
9	3.16188467	138.846
10	3.58888811	138.071
11	4.08388848	138.509
12	4.57933334	140.130
13	5.14918831	140.172
14	5.88818883	140.822
15	6.46508423	142.851
16	7.24688277	142.706
17	7.91858806	142.361
18	8.64888578	142.418

19	9.41[illegible]134	141.0[illegible]
20	10.[illegible]	140.1[illegible]
21	10.[illegible]	[illegible]
22	11.[illegible]	137.4[illegible]
23	12.[illegible]	137.[illegible]1
24	12.[illegible]1114	137.[illegible]
25	13.[illegible]	13[illegible].4[illegible]
26	13.[illegible]	13[illegible]
27	14.[illegible]	13[illegible]
28	15.[illegible]	14[illegible].167
29	15.[illegible]	14[illegible]
30	16.[illegible]	13[illegible]
31	16.[illegible]	13[illegible]
32	17.[illegible]	13[illegible]
33	17.[illegible]	13[illegible].037

HOPKINSON BAR--TENSILE
500 STRAIN/SEC
420 STAINLESS STEEL
SPEC SS-5

1	.70[illegible]	106.194
2	.73[illegible]74	110.[illegible]
3	.77057471	117.[illegible]
4	.8[illegible]	121.[illegible]
5	1.[illegible]	125.[illegible]
6	1.[illegible]	128.[illegible]
7	1.[illegible]1	131.[illegible]
8	1.57761007	132.046
9	2.[illegible]13[illegible]	13[illegible].864
10	2.67[illegible]1	130.918
11	2.[illegible]7	130.153
12	3.37[illegible]	[illegible]
13	3.7[illegible]	[illegible]
14	4.[illegible]747618	[illegible]
15	4.[illegible]	131.114
16	5.[illegible]1	133.051
17	6.[illegible]11	135.190
18	6.[illegible]1	136.037
19	7.3[illegible]14876	137.070
20	7.[illegible]13	138.117
21	8.3[illegible]	138.161
22	8.91174777	138.211
23	9.4[illegible]	137.470
24	9.[illegible]	137.118
25	10.[illegible]735	135.568
26	10.[illegible]	135.685
27	11.57434021	135.293
28	11.[illegible]5444	134.931
29	12.4[illegible]	135.378
30	12.[illegible]	136.210
31	13.47061113	137.000
32	14.12047528	137.580
33	14.79461377	137.188
34	15.[illegible]173	136.040
35	15.81079407	136.102
36	16.1[illegible]	134.505
37	16.4[illegible]	130.[illegible]
38	16.70611278	131.441
39	16.[illegible]	129.478

HOPKINSON BAR--TENSILE
500 STRAIN/SEC
8AL-1MO-1V TITANIUM
SPEC TI-1

1	1.72061024	183.716
2	1.80700758	187.2[illegible]
3	1.84607857	191.653
4	2.00035116	196.814
5	2.19409128	201.183
6	2.50525211	206.746
7	2.85456300	209.136
8	3.18003505	208.747
9	3.43548373	207.983
10	3.82009723	207.181
11	4.28161527	205.608
12	4.74022163	204.035
13	5.23453837	202.859
14	5.57543134	201.000
15	5.90011878	201.092
16	6.32812319	201.702
17	6.77020001	202.509
18	7.14027441	202.917
19	7.58034093	203.325
20	7.96384206	203.735
21	8.51540046	204.149
22	9.02772368	204.165
23	9.57323678	205.769
24	9.86300189	206.174
25	10.29064025	205.395
26	10.87184352	204.223
27	11.30136496	202.253
28	11.90690672	198.702
29	12.36751834	195.940
30	12.79007737	193.177
31	13.17754640	190.016
32	13.56272605	186.855
33	13.77060076	183.291
34	14.12008181	179.732
35	14.36474801	174.583
36	14.60772450	170.228
37	14.74057050	166.662
38	14.91944015	163.891
39	15.05756024	161.515
40	15.09259945	158.740

HOPKINSON BAR--TENSILE
560 STRAIN/SEC
8AL-1MO-1V TITANIUM
SPEC TI-2

1	1.18216133	182.695
2	1.21006670	185.479
3	1.21055790	188.264
4	1.24522094	190.641
5	1.27031792	193.821
6	1.31139595	197.001
7	1.30590239	199.776
8	1.42075585	201.306
9	1.73001692	203.432
10	2.23505459	205.517
11	2.54640073	205.580
12	2.85771275	206.247
13	3.12934476	204.906
14	3.51425069	205.381
15	3.80009237	205.453
16	4.31783085	206.340
17	4.84873655	207.641
18	5.52709632	209.369
19	5.90439913	209.051
20	6.50245592	209.971
21	6.87610339	209.654
22	7.50833873	208.995

23	[illegible]	[illegible].717
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27	10.[illegible]	[illegible]
28	10.[illegible]	[illegible].317
29	11.[illegible]	[illegible].716
30	11.[illegible]	[illegible]
31	12.[illegible]	[illegible]
32	12.[illegible]	[illegible]
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41	14.[illegible]	[illegible]
42	14.[illegible]	[illegible]

HOPKINSON BAR--TENSILE
[illegible] STRAIN/SEC
[illegible]-1MO-1V TITANIUM
SPEC TI-3

1	.[illegible]	[illegible].514
2	.[illegible]	[illegible]
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16	5.[illegible]	[illegible].471
17	6.[illegible]	[illegible]
18	6.[illegible]	[illegible]
19	7.[illegible]	[illegible]
20	7.[illegible]	[illegible]
21	[illegible]	[illegible]
22	9.17[illegible]	[illegible].119
23	9.[illegible]	[illegible]
24	10.[illegible]151	[illegible]
25	10.[illegible]	[illegible]
26	11.[illegible]	[illegible]
27	11.[illegible]	[illegible]
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29	12.[illegible]	[illegible]
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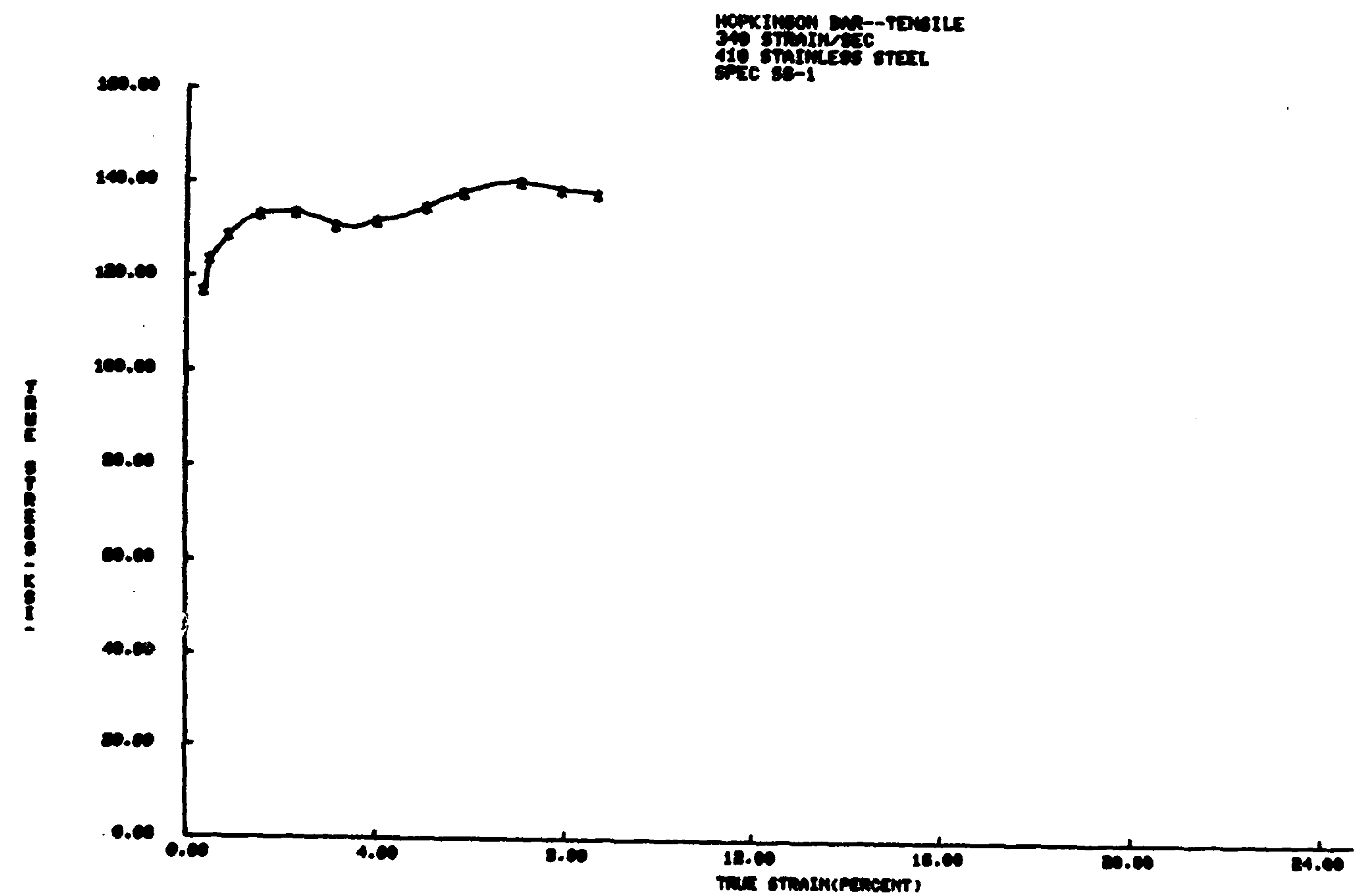
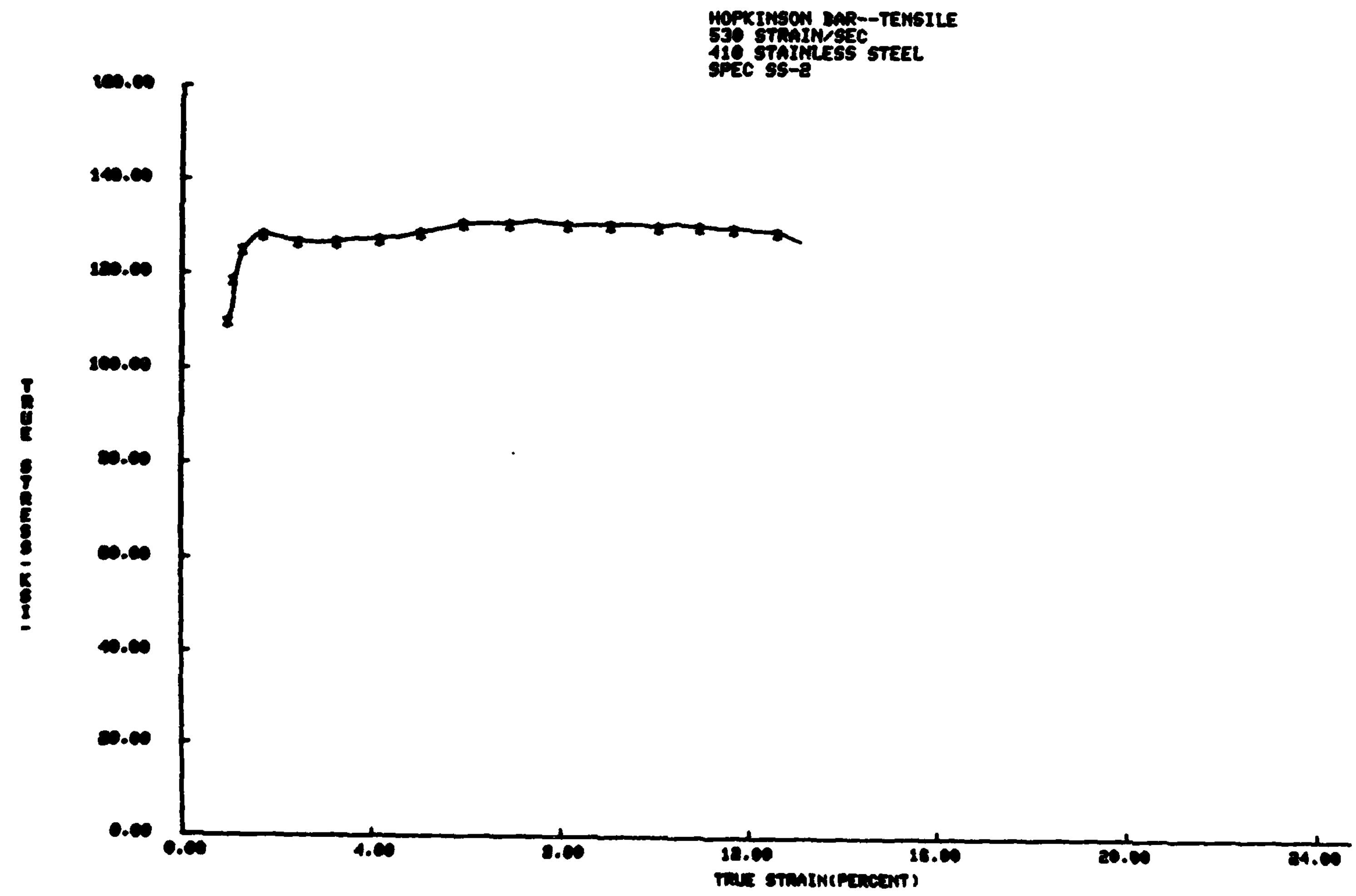
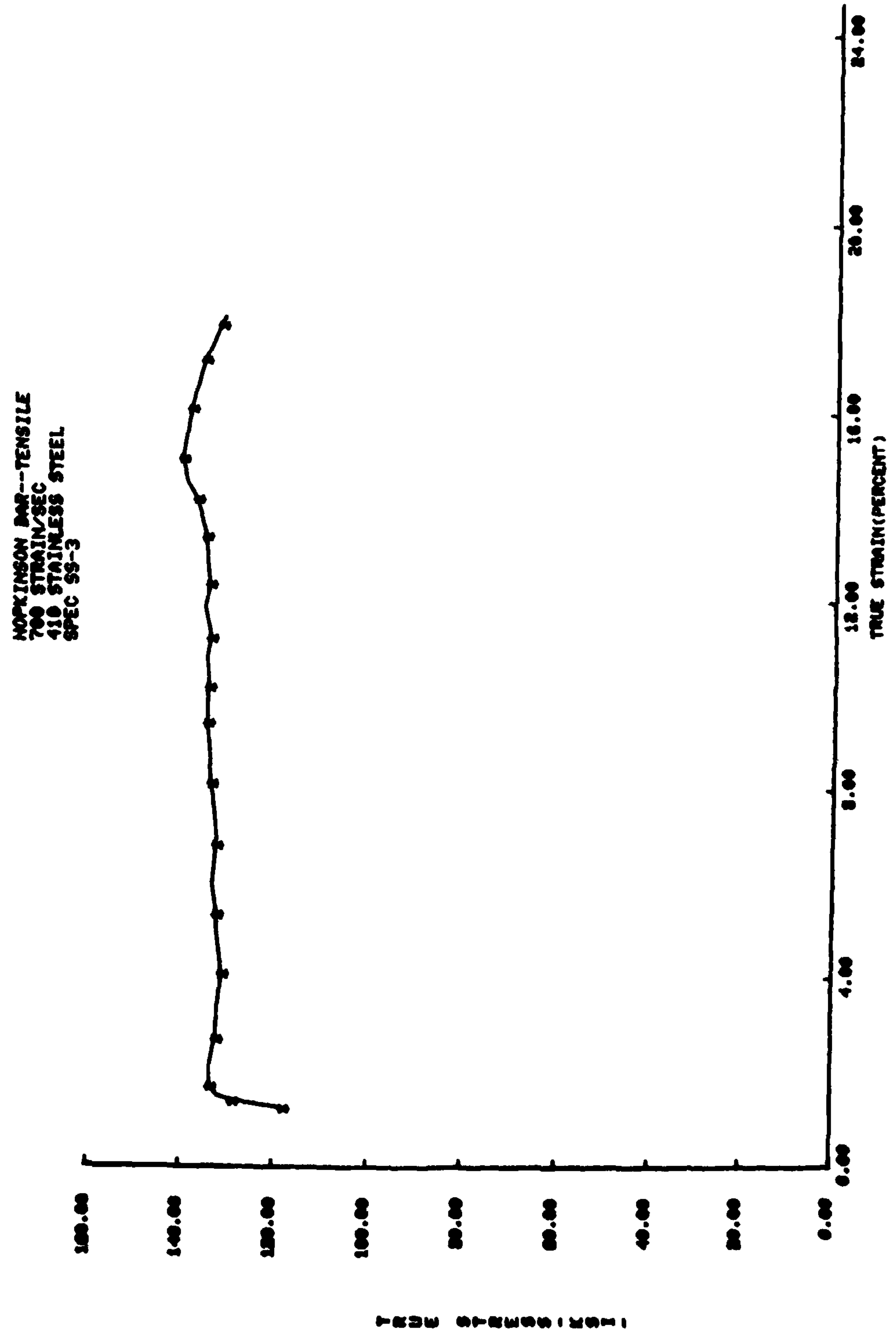

HOPKINSON BAR--TENSILE
340 STRAIN/SEC
410 STAINLESS STEEL
SPEC SS-1
TRUE STRESS(KSI)
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
TRUE STRAIN(PERCENT)


HOPKINSON BAR--TENSILE
530 STRAIN/SEC
410 STAINLESS STEEL
SPEC SS-2
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
TRUE STRESS(KSI)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
TRUE STRAIN(PERCENT)


HOPKINSON BAR--TENSILE
700 STRAIN/SEC
410 STAINLESS STEEL
SPEC SS-3
TRUE STRAIN(PERCENT)
TRUE STRESS(KSI)
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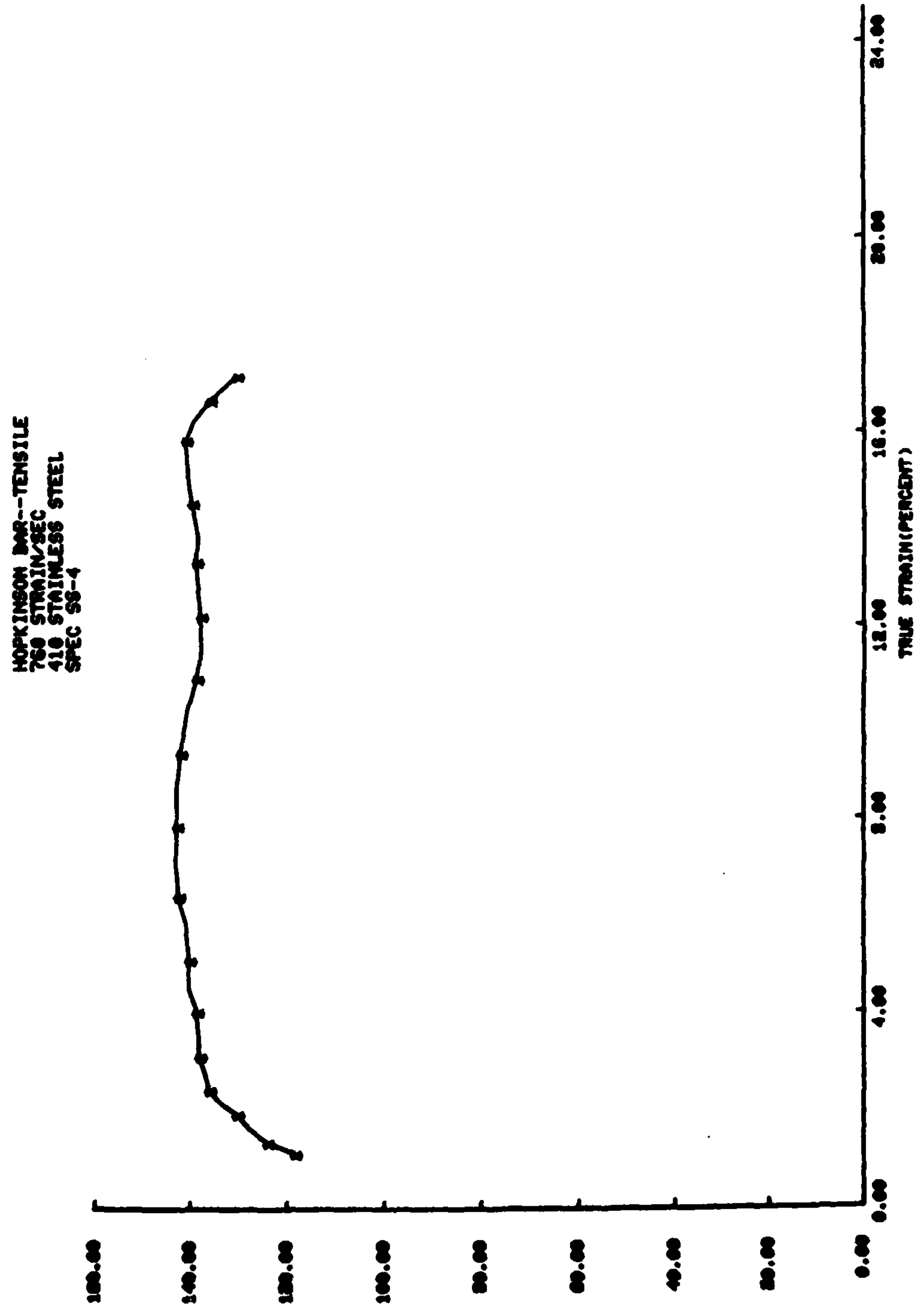
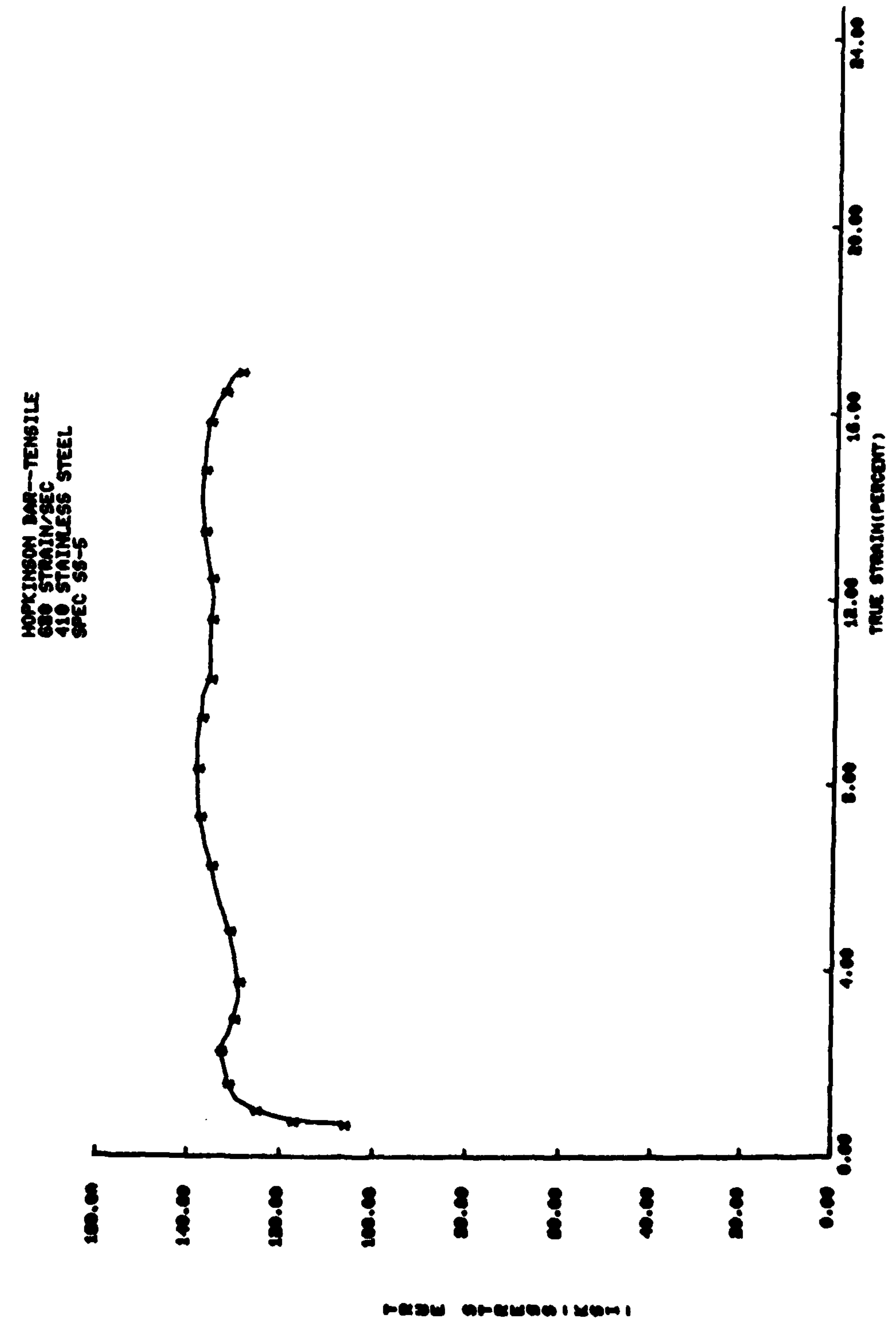
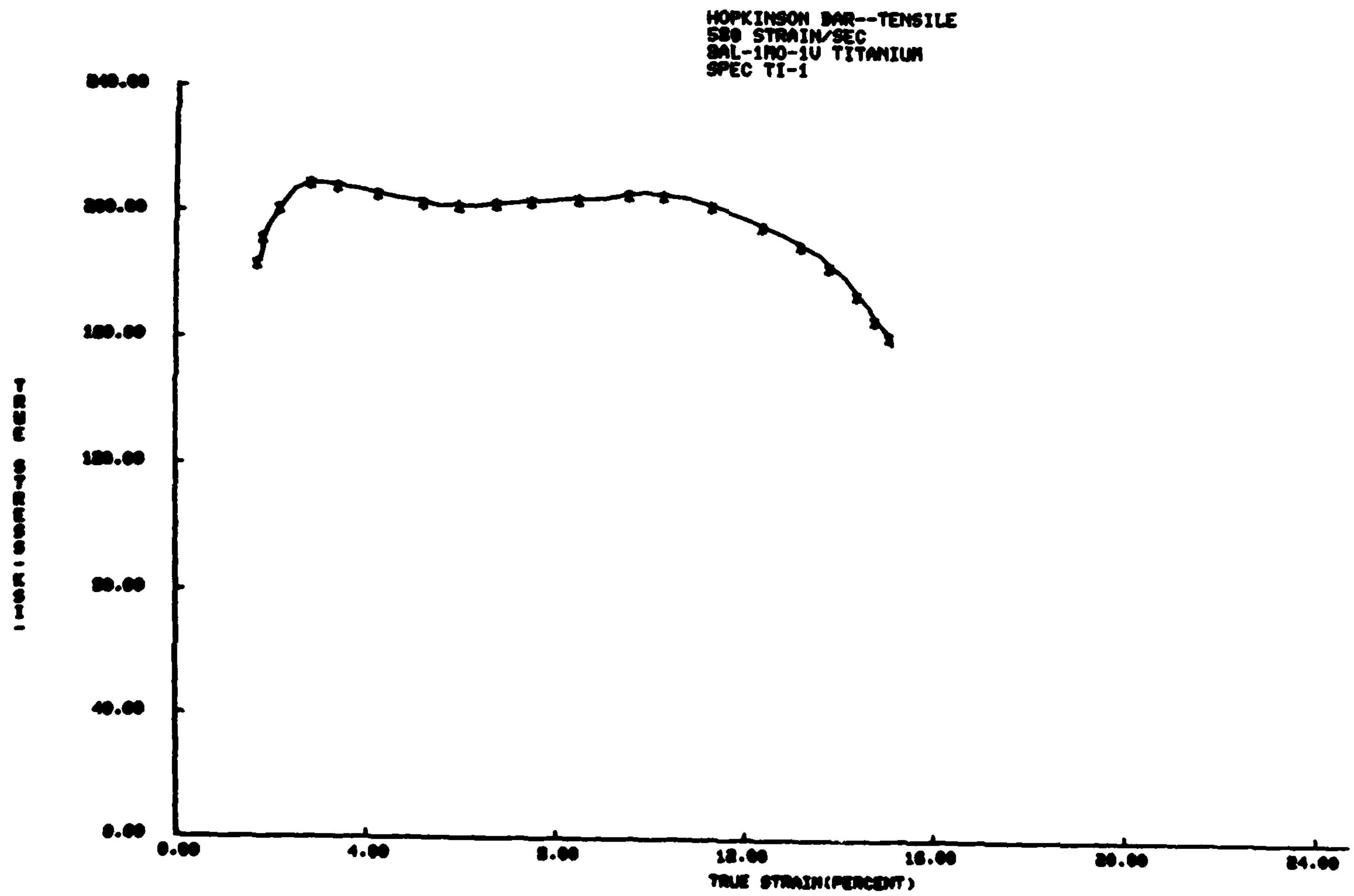
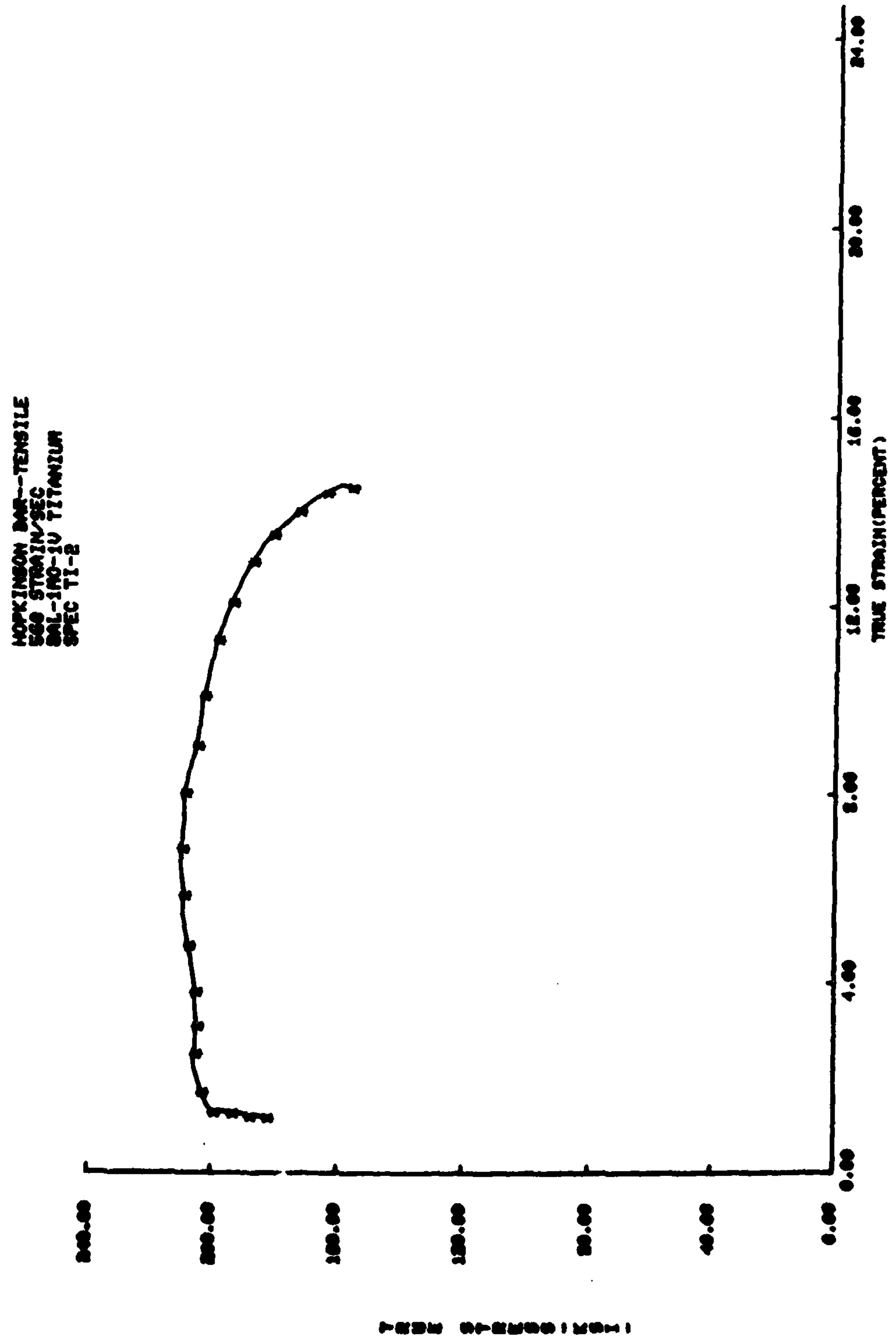
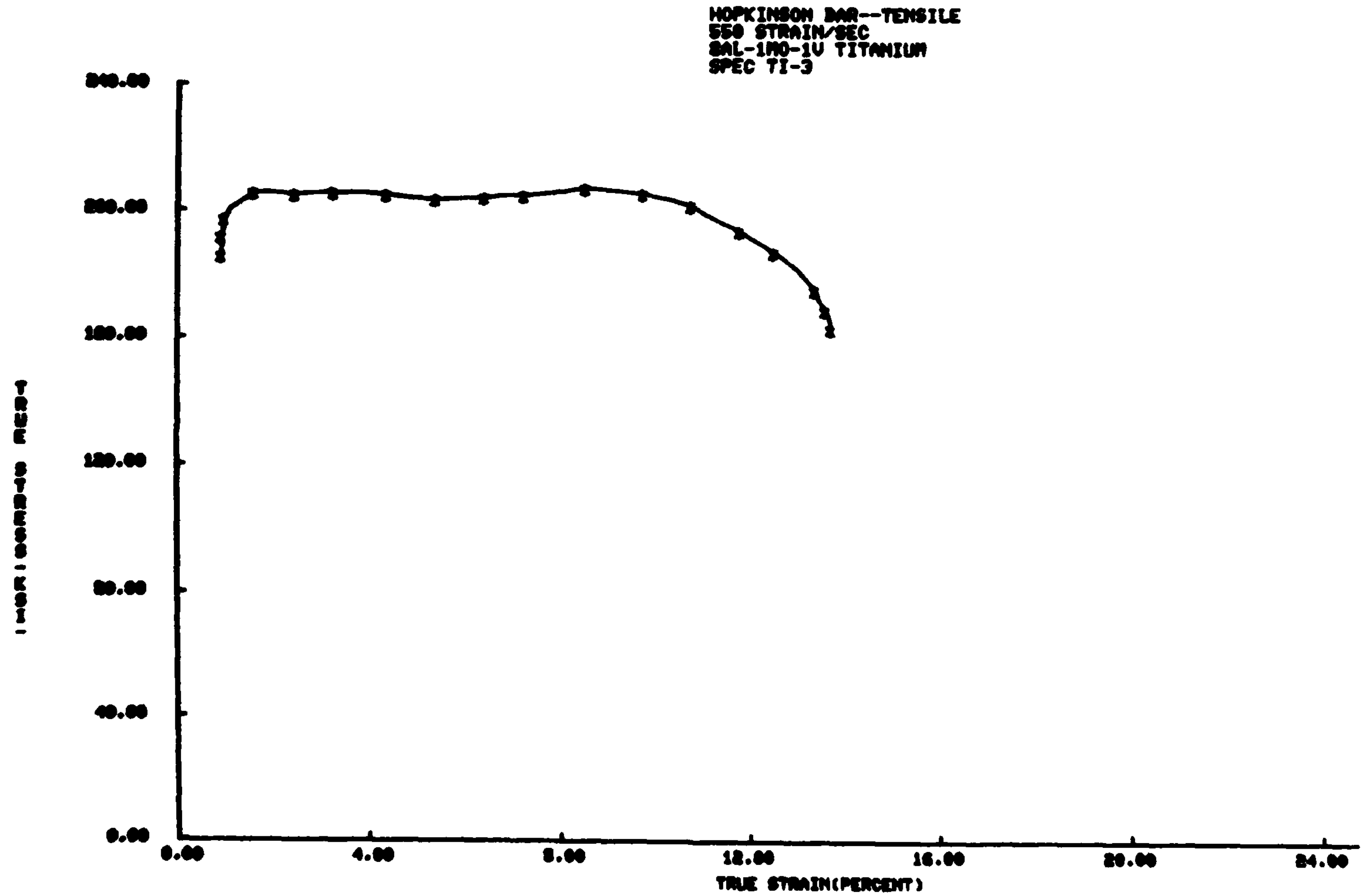
4.00
8.00
12.00
16.00
20.00
24.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00


HOPKINSON BAR--TENSILE
760 STRAIN/SEC
410 STAINLESS STEEL
SPEC SS-4
TRUE STRAIN(PERCENT)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00


HOPKINSON BAR--TENSILE
600 STRAIN/SEC
410 STAINLESS STEEL
SPEC SS-5
0.00
4.00
8.00
12.00
16.00
20.00
24.00
TRUE STRAIN(PERCENT)
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00


HOPKINSON BAR--TENSILE
580 STRAIN/SEC
8AL-1MO-1V TITANIUM
SPEC TI-1
TRUE STRESS(KSI)
240.00
200.00
160.00
120.00
80.00
40.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
TRUE STRAIN(PERCENT)


HOPKINSON BAR--TENSILE
500 STRAIN/SEC
8AL-1MO-1V TITANIUM
SPEC TI-2
0.00
4.00
8.00
12.00
16.00
20.00
24.00
TRUE STRAIN(PERCENT)
0.00
40.00
80.00
120.00
160.00
200.00
240.00


HOPKINSON BAR--TENSILE
550 STRAIN/SEC
8AL-1MO-1V TITANIUM
SPEC TI-3
TRUE STRESS (KSI)
240.00
200.00
160.00
120.00
80.00
40.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
TRUE STRAIN(PERCENT)

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